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ECONOMIC GEOLOGY

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THE GEOLOGY OF THE RADIUM HILL URANIUM MINE, SOUTH AUSTRALIA

L. W. PARKIN AND K. R. GLASSON

ABSTRACT

The Radium Hill mine, originally worked on a minor scale for its radium content, has been intensively tested by drilling, sampling and exploratory development over the past ten years, and is now a significant producer of uranium ore. The ore mineral, which is the titanium uranium complex davidite, occurs in association with rutile, ilmenite, bronze biotite and quartz in a series of subparallel lodes that are late stage replacements in fracture planes located near the axial plane of a regional fold in early Precambrian metasediments. The strike of the shears is slightly undulatory, and dips range from 40° to 70°.

The distribution of the ore within the lode channels is in irregular shoots though with some suggestion of overall pitch.

The area has been a locus for numerous phases of igneous activity, some of which are considered significant in the localization of ore.

CONTENTS

	PAGE
Introduction	815
Previous publications	816
Regional geology	818
Mine geology	818
Structural control	824
Acknowledgments	825
References	825

INTRODUCTION

THE Radium Hill mining field is situated in the east central part of the State of South Australia, 320 miles from the State Capital, Adelaide, 200 miles from the nearest sea port—Port Pirie, and 60 miles southwesterly from the lead-zinc mines at Broken Hill (Fig. 1). The mine lies within fifteen miles of the road and railway that serve Broken Hill from Adelaide. The area is one of low and spasmodic rainfall, the annual average being 7½ inches, mostly recorded by irregular thunderstorms. Temperature ranges are extreme: summer day temperatures exceed the 100° F for prolonged periods; frosts are not

uncommon in winter. The area is given over to sheep pasturing. The topography is undulating, with deep weathering and only isolated remnant rock outcrops.

The original discovery of the field was made in 1906 when a claim was pegged and considerable interest aroused in the suite of rare radioactive minerals. The claim was worked until 1908 and then abandoned. Taken up again in 1909, activity continued until 1915, in which period numerous shafts were sunk, a magnetic concentrating plant erected, and several parcels of concentrates sent abroad for metallurgical investigation. A treatment works was built in Sydney and some 350 milligrams of radium bromide produced from 95 tons of concentrates. The area was abandoned from 1915 to 1923 when a new company was formed with the principle object of producing titanium white. The project failed and all work ceased in 1931. In 1941 an investi-

FIG. 1. Locality Map showing Radium Hill.

gation was undertaken on behalf of a Melbourne company but no action followed.

The present phase commenced in 1944 when a detailed geological survey was undertaken and recommendations for complete testing were made. In 1946 the first diamond drilling commenced and later shaft sinking was undertaken for metallurgical testing. Since that time the work progressed with increasing tempo to the point where at present the mine is ready for full scale production.

PREVIOUS PUBLICATIONS

Early reports on the Radium Hill area deal exclusively with mineralogical investigations and early mining and prospecting operations. The first detailed study of the field is that of Mawson (2) in which the geological setting of the occurrence is discussed and mineralogical and petrological details described. Sprigg and Whittle (3) of the South Australian Department of Mines have been responsible for a comprehensive Bulletin published by the

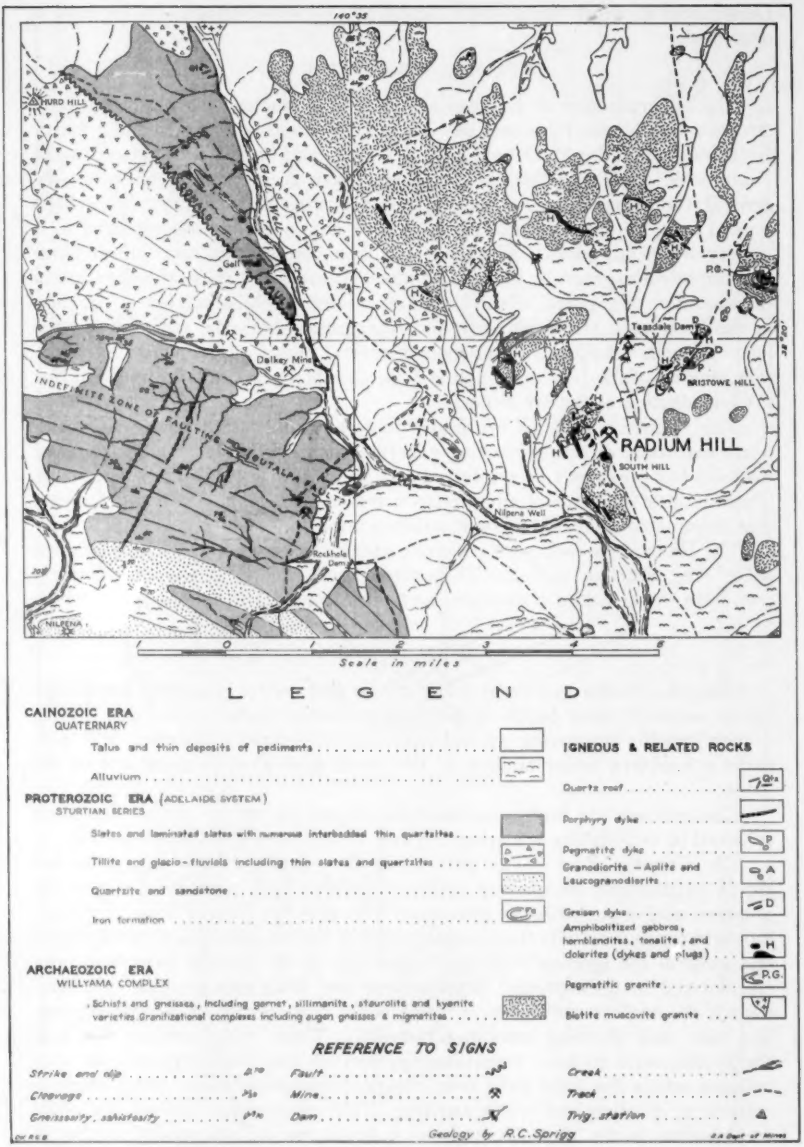


FIG. 2. Geologic map of the vicinity of Radium Hill, South Australia.

Department in which the geology, petrology and mineragraphy of the field is described.

REGIONAL GEOLOGY (FIG. 2)

The mineralization at Radium Hill occurs in fracture plane structures in Archaean sedimentary gneisses and igneous intrusions one mile east of a major fault lineament (the McDonald Hill Fault), which in this area separates the Proterozoic (Adelaide System) sediments from the Archaean gneisses. In general, the rocks of the Archaean group comprise metasediments of perhaps several ages, in places extensively granitized and commonly accompanied by a variety of igneous rocks. The basic intrusives comprise an early sill or plug-like amphibolite, generally talcose and much sheared with mineral elongation in the direction of regional schistosity; and a later amphibolite that is common in the McDonald Hill fault area, and transgresses both the gneisses and the lode channels. Acid intrusions include several phases of pegmatite introduction, one of which is a sodic aplitic type possibly genetically responsible for the introduction of the ore mineral.

The Archaean gneisses are folded in steep limbed structures, with east-north-east axial direction pitching generally at a low angle. Overturning of the folds has previously been inferred (3) but is now known to be exceptional. There is little evidence of any effect on these basement rocks of the orogeny that terminated Adelaide System sedimentation.

The Proterozoic sediments comprise quartzites, slates, and a well developed tillite (the Sturtian tillite). They are broadly folded along southwesterly axes with marked drag phenomena as the McDonald Hill fault is approached.

MINE GEOLOGY

General.—Surface outcrops are sparse so that earlier geological knowledge has of necessity been based on rather fragmentary data, a condition which, though steadily improving as underground development proceeds, still prevents a confident understanding of the whole geological environment of the lodes.

The gneisses are highly metamorphosed and as yet no success has been achieved in establishing a marker horizon, or any stratigraphic succession.

The Country Rock.—The gneisses in the vicinity of the mine area are highly pegmatized, comprising aplitized gneisses and quartzites, migmatitic gneisses, and some schistose gneisses. The area has been a locus for more intensive igneous activity than is recognized in the immediately adjacent region and most of the igneous rock types observed on the surface have now been encountered in underground development, and their relationships observed. Clearly the earliest of these is an amphibolite type having an elongated plug-like form and showing marked schistosity. These rocks predate the lode shears and seem to have been favorable loci for ore emplacement. In each instance where the lodes have been observed traversing these rocks, there is marked up-grading and width swelling. The exposure of one of the older amphibolites in the Main Shaft shows a dip at the contact parallel to that of the gneisses.

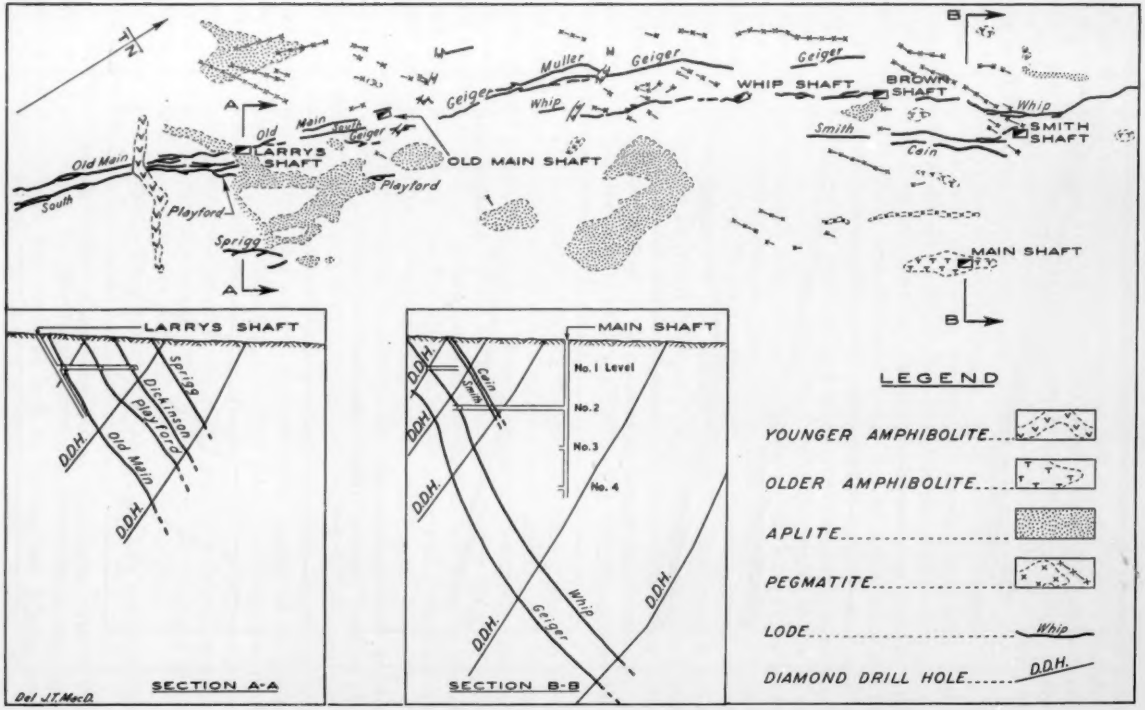
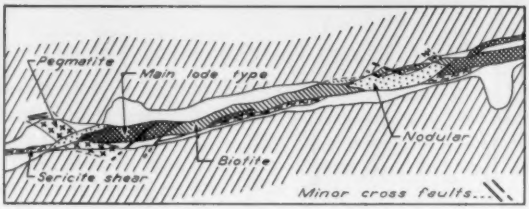
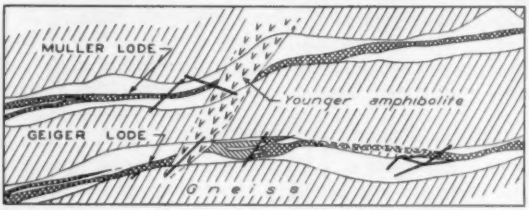


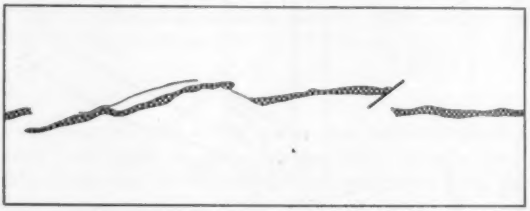
FIG. 3. Surface plan and sections of the Radium Hill mine showing lode system and igneous intrusions.



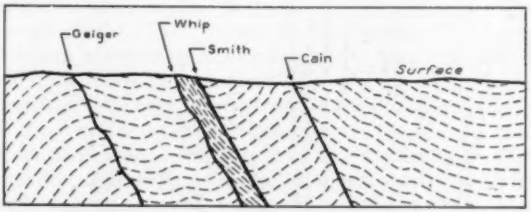
(a) PLAN SHOWING LODE TYPES



(b) PLAN SHOWING RELATIONSHIP OF YOUNGER AMPHIBOLITE TO LODE AND GNEISSES



(C) PLAN OF ECHELON ARRANGEMENT OF WHIP LODE NO.2 LEVEL



(d) DIAGRAMMATIC CROSS-SECTION LOOKING NORTH SHOWING RELATIONSHIP OF SHEARS TO FOLDING

Del. A.M.C.S.

FIG. 4.

The only other basic intrusive is a younger amphibolite or uralite dolerite. These show a lesser degree of alteration and post date the lodes, although they are possibly associated with the final pyrite mineralization (Whittle—in press). They are dike-like intrusions cutting across all other formations, including the lode. Excellent relationships have been observed on the No. 1 level where the amphibolite cuts directly across the lode (Fig. 4, b). Also farther southwest there is evidence of the amphibolite transgressing one of the later pegmatite dikes. In some drill cores the younger amphibolites show a gradational contact with the enclosing gneiss. Their trend roughly corresponds to that of cross faulting and shearing directions recognized in the lode system and they have probably been emplaced along zones of weakness of this kind.

The acid intrusions comprise soda microgranites (aplites) and associated pegmatites that have been observed underground in gradational inter-development. These rocks exhibit both concordant and transgressive habits, in some exposures the pegmatites closely follow the lode channel where they preserve some of the structure of the lode shear, though with considerable ore impoverishment. The fact that the soda aplites carry rare earth accessory minerals has led to the suggestion that they may be of genetic significance in ore emplacement. There is no direct evidence in support of this inference, in fact there is normally a notable absence of uranium mineral within their borders. Whittle's paragenetic studies (in press) have indicated that these rocks were introduced during an inter-ore mineralization period, overlapping into the period of uranium mineral emplacement.

Country Rock Structure.—Surface mapping has shown that the gneisses are folded into an anticlinal structure pitching north-easterly at a low angle. Underground exposures generally show a gentle south-westerly pitch in the more central portions of the mine, but north-easterly pitch is observed towards the northern extremity. It appears that this anticline is the major structural unit with the southern limb exhibiting important minor fold phenomena which have provided additional planes of weakness important as ore loci (Fig. 4d).

Faulting and fracturing of the country rock has probably been influenced by the fold structure, and in general the strike of the major fracture planes is closely parallel to, and may partly coincide with, that of the fold axial planes. In detail, however, the fracture planes gradually transgress the fold structure and locally dip at angles that may be as much as 90° to that of the gneisses. An earlier interpretation (3) has suggested that these planes represent the loci for overthrust axial plane movement. However, there is little evidence of overthrusting, in fact most observations would suggest tensional movement. Cross faults, generally of a minor nature, offset both the folds and the lode fractures, normally causing ore impoverishment in the vicinity.

The Lode Structure.—The pattern of the recognized lode system is shown in Figures 3 and 4.

Investigations so far have established three major lodes, namely Whip, Geiger and Old Main. In close association and parallel in dispostion are five smaller lodes that have been explored both by drilling and driving, namely Playford, Smith, Muller, Dickinson and South Lodes. Besides these ore bodies, there are prospects to the north-east of Bonython Hill, Taylor's Hill

and Bristowe's Hill and to the south-west is another lode (Rutile lode) which has been intersected on the foot wall side of Old Main lode. To the southeast are several minor lode systems known as the Valley lode and the South Hill lodes, and to the north-west is a small lode fracture on which a shaft (West Shaft) was sunk by early prospectors.

Some of these lodes were established in the first instance by surface workings and as the bulk of the intervening terrain is obscured by many feet of alluvial and residual cover, there is every prospect that the lode system is even more extensive than is at present appreciated.

Two main strike directions are recognized, namely north 57° E and more dominantly north 47° E. Dips range from 30° to 70° in a south-easterly direction, the flatter angle being generally confined to the central and upper portion of the system.

The two major strike directions correspond to those of axial planes and bedding foliation. In a general way, the lode fractures transgress the fold structures by a series of steps, the bedding foliation plane direction dominating, then stepping over on an axial (cleavage) plane before again resuming bedding direction. This simplified pattern is commonly obscured by oblique offsets on faults. All recognized mineralized planes are confined to the southerly limb of the major anticlinal structure, and to the corresponding limb of the associated minor folds.

The pitch behavior on the lode system is not clearly understood. Mineralization on Whip lode appears to progress to the north with depth, and there is also an apparent progression in a southerly direction on Old Main and South lodes at the southern end of the field.

Borehole data allows of no simple definition of pitch trends. The mineralization within the developed ore shoots is subject to erratic variations so that the interpretation of diamond drill results is a hazardous undertaking. If in fact the mineralized fracture planes are related, as suggested above, to axial and bedding planes, then the intersection of these planes might be expected to have some control on lode pitch behavior. This may prove to be the case.

Lode Mineralization.—The uranium ore mineral is davidite which was first described and named by Mawson (1). It occurs in intimate intergrowth with rutile, ilmenite, hematite, and some magnetite, in an ore in which each of these minerals occurs in varying proportions. A detailed discussion of the intergrowth and exsolution phenomena is presented by Whittle (in press).

The mineralization of each of the known lodes is essentially similar. Each shows a gradation from incipient sericite development by gradual stages, towards coarse ilmenite biotite growth. Four lode types are recognized and the proportions of these types present varies from lode to lode (Fig. 4). A typical lode channel commences as a shear in which there has been a segregation of augen of biotite and quartz enclosed in banded gneiss. Introduction of iron and titanium (with or without uranium) mineralization into these knots or augen produces an ore type known locally as nodular or spotted ore. An increase in the degree of initial fracturing or brecciation allows a higher degree of replacement resulting in the so called main lode ore type, which is a coarse

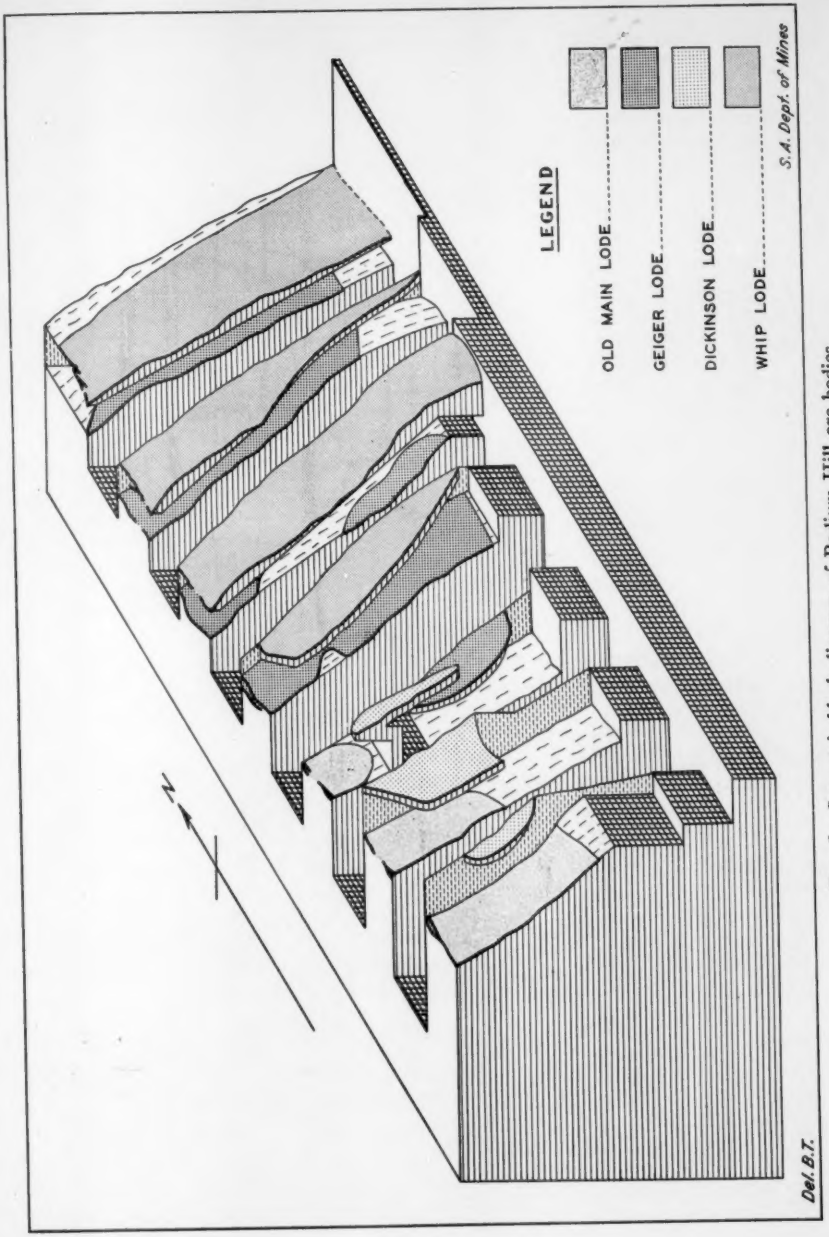


FIG. 5. Isometric block diagram of Radium Hill ore bodies.

intergrowth of bronze biotite, pinkish quartz, ilmenite, rutile, hematite and davidite.

The gradation from nodular ore to main lode ore is generally progressive from the extremities of each lode towards the centres, though locally there may be a considerable intermixing of the two types. Absence of iron and titanium mineralization results in a barren bronze biotite lode which is sufficiently characteristic to be recognized as a third lode type. The fourth type has been called the Valley lode type and is well exhibited by the Dickinson lode. In this there does not appear to have been such intense brecciation, but the rock type has been heavily silicified and there is essentially an absence of biotite. It is rich in rutile and hematite, but the davidite is much more variable. Indeed, in the actual Valley lode type as initially described by Whittle, there was no davidite detected.

In dealing with all these lode types, Whittle has emphasized that there has been very little introduction of new material except for iron, titanium, uranium, and magnesium and the change in gangue and mineral type has not been due entirely to metasomatic replacement, but has involved a redistribution and subsequent recrystallization of silicious, aluminous, and alkali materials from the original fracture plane.

Since the primary uranium mineralization is confined to the mineral davidite in extremely sporadic intergrowth with rutile and ilmenite, a nodular lode type may contain relatively high grade uranium mineralization whereas a main lode type, though rich in rutile and ilmenite, may locally be low in uranium.

Whittle has suggested a paragenetic sequence that commences with hematite, ilmenite and rutile associated with biotite gangue.

This is followed by the period of soda aplite intrusion which concludes with the introduction of davidite. Finally, there is a period of sulphide mineralization—pyrite and chalcopyrite—which may post date the emplacement of the younger amphibolites.

STRUCTURAL CONTROL

The ore bodies at Radium Hill are probably influenced by the directions of fracturing and faulting located near the axis, and on the southeast limb of a flat-pitching anticline. There are two distinct sets of fractures—a "Main" system striking N 57° E and a second set striking N 47° E. These two directions probably represent axial plane cleavage and bedding foliation, and the warping and rolling of the lodes is thought to be due to minor folding associated with a highly contorted limb of the anticline. The intersection of these two systems may control the general pitch of the lodes.

The lodes are fissure types and hence are independent of control by primary structure.

The over-all pitch of the ore shoots has not yet been established with any degree of certainty except that Whip lode is known to have an apparent steep pitch in a northerly direction. The pitch of individual rock types, shears, rolls, flutings, all seem to be flat, north-east or south-west and have little relationship to the over-all pitch of the ore shoots themselves.

Lateral control of mineralization within each lode has not been established. It is thought to be related to the degree of fracturing or permeability of the original fracture plane, but seems to be unrelated to any particular attitude in space. It seems not unlikely that the soda microgranite may be genetically related to mineralization, and if so it might be expected that there would be a zoning of mineralization influenced by the position of the microgranitic intrusion.

ACKNOWLEDGMENTS

The authors wish to thank S. B. Dickinson, Director of Mines and Government Geologist for South Australia, for permission to publish this paper and for suggestions and criticisms in its preparation. The initial investigation of the geology of Radium Hill and district has been done by R. C. Sprigg, and inevitably his work will form the basis for all subsequent contributions. The present authors, though differing with him in many of his interpretations, have drawn freely upon his field mapping and structural conceptions. The petrological and minerographic studies carried out by A. W. G. Whittle provide a factual record of the ore forming process that has found general acceptance, and the use of which is here gratefully acknowledged.

South Australia Dept. of Mines, and
Radium Hill Project,
Australia
March 12, 1954.

REFERENCES

1. Mawson, D., 1906, On certain mineral species associated with carnotite in the radioactive orebody near Olary: Trans. Roy. Soc. S. A., vol. 30.
2. Mawson, D., 1944, The nature and occurrence of uraniferous mineral deposits in South Australia: Trans. Roy. Soc. S. A., vol. 68.
3. Sprigg, R. C., and Whittle, A. W. G., in press, Uranium deposits in South Australia: Bull. 30, Geol. Survey of S. A.

URANIUM EXPLORATION BY THE BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS, IN THE RUM JUNGLE PROVINCE, NORTHERN TERRITORY, AUSTRALIA

N. H. FISHER AND C. J. SULLIVAN

CONTENTS

	PAGE
Abstract	826
Introduction	827
History	827
Regional geology	828
Types of deposits	831
Uranium-copper deposits	831
Autunite deposits	832
Quartz hematite veins	832
Hematite-limonite gossans	832
Laterites	832
Exploration techniques	833
Geological mapping	833
Airborne scintillometer surveys	834
Ground radiometric surveys	834
Self-potential, magnetic, and electro-magnetic surveys	835
Geochemistry	835
Costeaning	835
Diamond drilling	835

ABSTRACT

In the Rum Jungle uranium province (more correctly referred to as the Katherine-Darwin area) uranium occurs as replacement deposits, in places with copper and lead, in Precambrian sediments. Lesser deposits, in which uranium is associated with quartz and hematite, are found in shears in granite. Small copper-cobalt-uranium deposits have also been found in or near granite. Regional prospecting, based on air-photo geological mapping and airborne scintillometer surveys, is being systematically extended through the region, and may take 3 to 5 years to complete. As in Rhodesia and The Congo, particular formations are being found to be favorable for ore, and more detailed investigation of these formations is taking place. A private company, Territory Enterprises Pty. Ltd., is developing and mining deposits at Rum Jungle itself on behalf of the Commonwealth Government and other companies and syndicates are beginning to be active elsewhere in the district.

Tropical weathering of outcrops combined with soil and laterite cover complicates interpretation of surface radioactivity, and bulldozers are widely used to obtain good exposures; diamond drilling is the usual method for preliminary testing of the sulfide zone, which lies at depths ranging between 30 and 200 feet.

INTRODUCTION

THE area with which this paper deals and which will be referred to herein as the Rum Jungle Uranium Province is commonly known in Australia as the Katherine-Darwin region. It is situated in the northern portion of the Northern Territory of Australia, and as far as is known at present, it extends between lat. 12°40′ and 14°18′ S, and long. 130°35′ and 132°30′ E. Rum Jungle itself, the present centre of uranium mining, is approximately 55 miles south-south-east of the port of Darwin, from which a 3′6″ gauge railway ex-

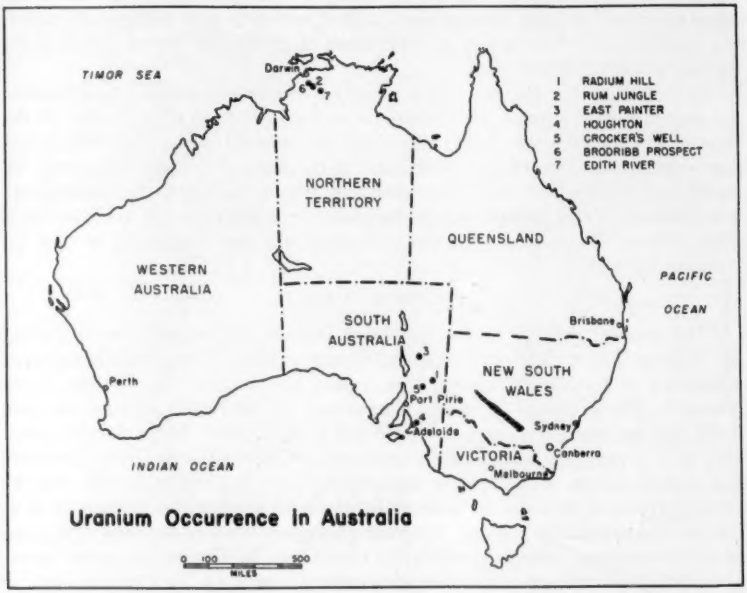


FIG. 1. Uranium occurrences in Australia (general map).

tends for 360 miles to the south-east. A highway runs from Darwin to Alice Springs nearly 1,000 miles to the south (Fig. 1).

The uranium province is situated in the summer rainfall area and the monsoonal wet season lasts from November to April, inclusive.

HISTORY

Gold was discovered in the province in 1869 and between then and 1900 a good deal of prospecting and small scale mining were carried out. Much of the work was done by Chinese, who first arrived in the district in 1875; more were given entry in 1886 in order to complete the railway line.

Up to the present the province has produced about 661,000 oz of gold, 7,000 tons of tin concentrate, 900 tons of wolfram concentrate, 11,500 tons of copper concentrate, 2,600 tons of silver-lead concentrate, and 12 tons of tantalite concentrate. The total value of its recorded production has been £3,300,000.

Uranium was discovered in old copper workings at Rum Jungle in September, 1949. Investigation of the discovery and of the surrounding country by the Commonwealth Bureau of Mineral Resources in the years 1950 to 1952 showed that important uranium deposits exist in the area and that others might possibly be found. At the beginning of 1953 the Rum Jungle area was taken over by Territory Enterprises Limited, which is now engaged in further exploration and in the mining and treatment of the known ore on behalf of the Commonwealth Government.

During 1952 the Bureau began a fairly intensive campaign of exploration for new deposits outside the immediate vicinity of Rum Jungle, and at the time of writing (August, 1953) this work has resulted in the discovery of one new deposit that may be important, and in the finding of numerous small deposits and radioactive anomalies, many of which remain to be investigated adequately. A few private prospectors have been active in the area and have made several discoveries. Mining companies are now beginning to take interest in the area.

REGIONAL GEOLOGY

The general geology of the Katherine-Darwin region has been described by Noakes (1).[1] The stratigraphic sequence begins with metamorphosed sediments of Lower Proterozoic age, called by Noakes "the Brocks Creek Group." These consist of shales, limestones, sandstones, conglomerates and tuffs, and are thought to exceed 15,000 feet in thickness. More detailed mapping now in progress will probably separate the Brocks Creek Group into several sub-divisions, separated by unconformities. The rocks of the Brocks Creek Group are intruded by numerous masses of granite and contain most of the ore deposits of the region. Current geological work is showing that some of the formational units into which the Group can be divided are more favorable for the occurrence of uranium than others.

A correlation seems to exist between particular sedimentary types and deposits of particular metals, but the stratigraphic knowledge of the region is as yet incomplete.

Uranium ore occurs mostly in fine-grained beds, particularly in graphitic shales, and the deposits are associated with deformation of the beds either by folding or faulting. The ore beds at Rum Jungle occur within half a mile of an intrusive mass of granite, but no deposits of importance have been found within the granite itself. Scintillometer surveys have shown that the Rum Jungle Granite is more radioactive than some others in the district, e.g., than the Litchfield Granite which extends from Bynoe Harbour to about lat. 14°S (Fig. 2) and they have also shown that the portion of the granite extending for about 4 miles north and 4 miles south of the Rum Jungle field is more radioactive than the other parts of the Rum Jungle Granite.

[1] Numbers in parentheses refer to References at end of paper.

Preliminary surveys in other parts of the province also show that those granites with which deposits of uranium-bearing minerals have been found to be associated are themselves fairly highly radioactive and there is a general indication that radioactivity of the granites is, as has been discussed by Gross (*2*), a broad guide to ore.

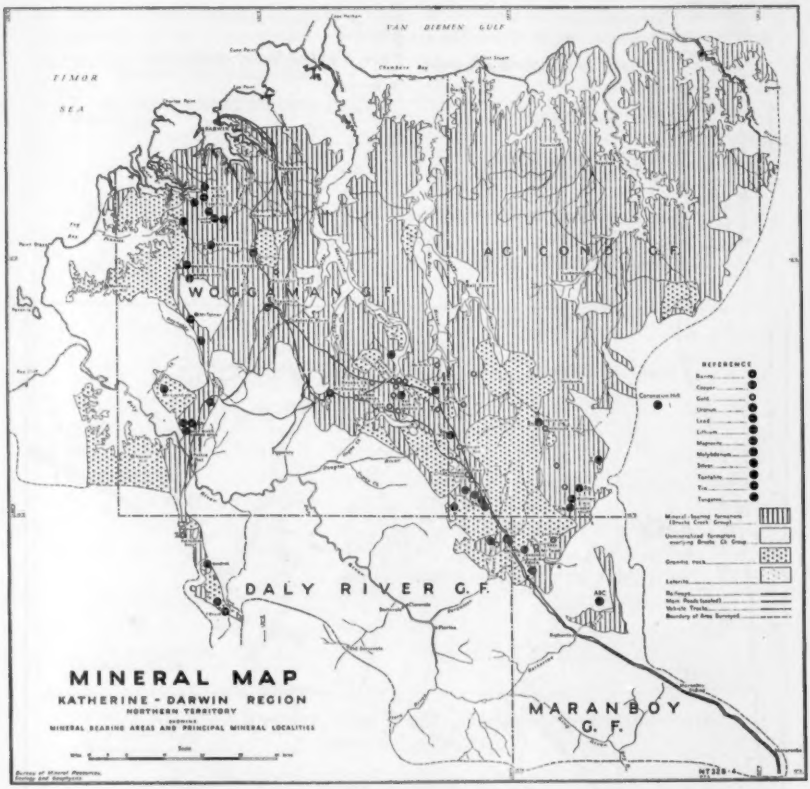


FIG. 2. Mineral map, Katherine-Darwin area, Northern Territory, Australia. (Location of uranium and copper deposits shown.)

The Brocks Creek Group is unconformably overlain by the Buldiva Quartzite of Upper Proterozoic age. This formation, which is thought to be about 4,000 feet thick, consists mainly of quartzite with some interbedded volcanic rocks, dipping at angles of less than 30 degrees. Until recently the Buldiva Quartzite had not been shown to carry any worth-while ore deposits and it was regarded as obscuring large areas of potentially ore-bearing country. However, important discoveries recently made in areas generally covered by

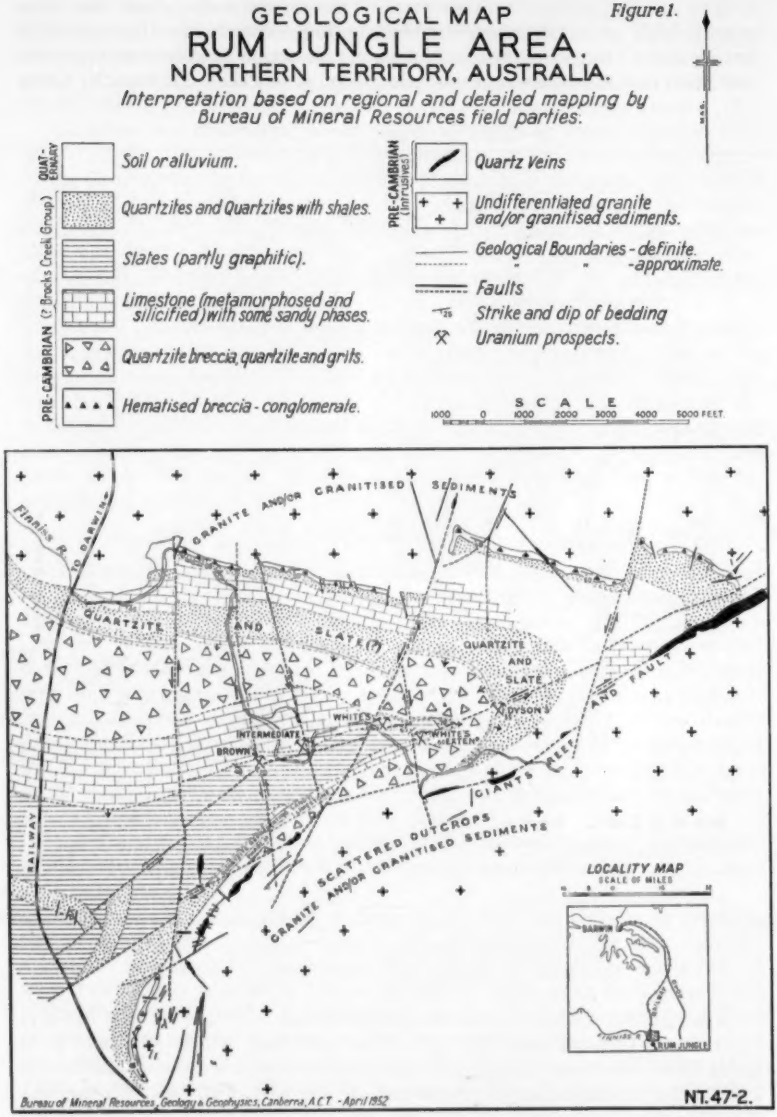


FIG. 3. Geologic map, Rum Jungle, Northern Territory, Australia.

Buldiva sediments, but where narrow belts of the underlying Brocks Creek Group rocks have been exposed by faulting, suggested that mineralization did actually extend into the Buldiva quartzite and the latest uranium discovery confirms this, as it occurs entirely in the volcanic rocks interbedded in the Buldiva Quartzite.

Cretaceous sandstones, lying horizontally and up to 200 feet thick, occur on mesas in the area, and laterite, mostly of Tertiary age, covers a considerable proportion of the older rocks. Deep soils inhibit prospecting in river valleys and on the wide alluviated planes.

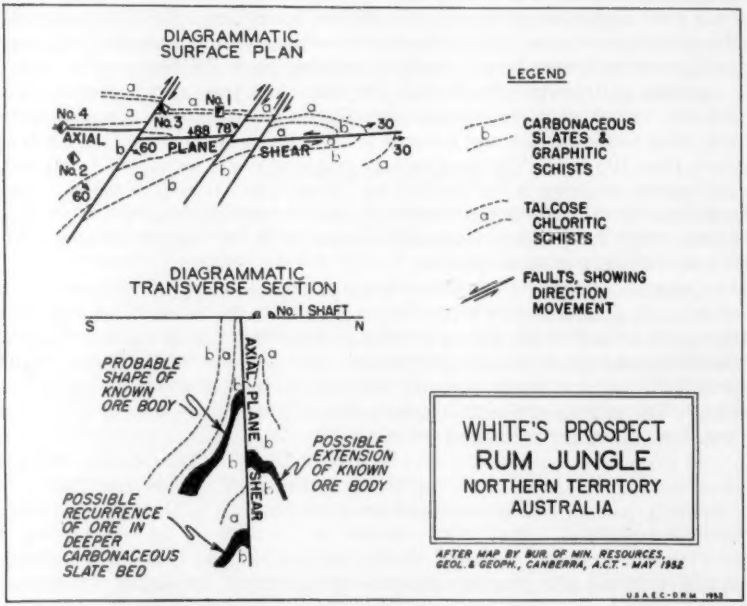


FIG. 4. White's Prospect, Rum Jungle, Northern Territory, Australia (plan and section).

TYPES OF DEPOSITS

The uranium deposits near Rum Jungle have been briefly described by Sullivan and Matheson (3). The main types of deposit so far found in the Katherine-Darwin area are described briefly below.

Uranium-Copper Deposits.—White's Deposit at Rum Jungle is typical of this group. In the primary zone the ore is generally highly folded graphitic slate, impregnated with chalcopyrite, pyrite, uraninite and bornite; chalcocite is also found. The ore minerals mostly replace bedding or cleavage planes but they are also associated with minor crosscutting quartz veins (Fig. 4).

At the surface this type of deposit is apt to be unimpressive at first sight. Little or no ferruginous gossan is present, but staining by copper carbonates may be seen. Radioactivity may amount to only four to five times background over a few hundred square feet.

If secondary uranium minerals are present they are generally yellow ochres with only minor torbernite and little or no autunite.

The outcrops of this type discovered to date have been close to river level where the present cycle of erosion has cut down through a plateau of possible Oligocene-Miocene age. It is believed that in Rhodesia leaching of both copper and uranium is more complete at peneplain level and only inconspicuous casts after copper minerals may be found on the surface. At White's Deposit the water table was only 20 feet below the surface, whereas beneath the plateau primary material may be at a depth of anything up to 200 feet.

Autunite Deposits.—At Dyson's Deposit, Rum Jungle, rich specimens of autunite (much of it iron-stained and difficult to recognize) occurred at or very close to the surface, and autunite is known to occur to a vertical depth of more than 100 feet. The host rock is graphitic shale, no copper is present, and quartz occurring in the footwall and hangingwall is rich in pyrite. Several other deposits of this type are known, but the primary ore has not yet been tested. The surface impoverishment, common to the copper-uranium ores, is not so evident in these deposits.

Quartz-Hematite Veins.—Many uranium deposits have been discovered in, or near, the granite known as the Cullen Granite, in the Edith River area near the southern end of the province. These deposits occur as narrow siliceous reefs composed partly of brecciated quartz and occupying sheared zones in the granite. They are mostly oriented north-north-west and dip steeply to the west. The uranium mineral is meta-autunite or torbernite and is associated with hematite in the brecciated quartz.

In many of the deposits, particularly those in which the uranium mineral is meta-autunite, apatite is an important constituent of the ore and fluorite is present in places. No intersections have yet been made of the primary ore in these deposits.

Hematite-Limonite Gossans.—Bodies of hematite and limonite containing, in places, 50 per cent iron may give rise to radiometric anomalies. The iron-oxide minerals are in places botryoidal, suggesting a transported origin. A considerable amount of radioactivity is associated with some of these outcrops but trenching and drilling have shown that they are generally underlain at shallow depth by leached rock containing only minute amounts of uranium.

The primary mineralization may consist of pyrite, constituting approximately 55 per cent of the rock, with very small amounts of uranium. These occurrences are similar to the surficial sheets of hematite, 1 to 5 feet thick, occurring at Mt. Painter, South Australia which contain torbernite in appreciable amounts, but are underlain by material with weak pyritic mineralization and a low uranium content.

Laterites.—A considerable number of radiometric anomalies detected by airborne scintillometer surveys have been found to correspond to flat sheets of pisolitic laterite. Ground investigation has shown that the ferruginous zone

of the laterite is commonly 2 to 3 times as radioactive as other rocks in the vicinity. This was also noted by one of the writers (C. J. Sullivan) in Rhodesia. Most of the radioactive laterite has no significance for ore. It is believed that the iron of the laterite has the property of fixing uranium from solutions that may come in contact with it. The source of this uranium is generally the small disseminated content of uranium in the underlying rocks, which is leached out by ground waters and brought to the surface during the wet season. The rise of the fluctuating water table ranges from the bottom of the oxidized zone, up to 200 feet in depth at the end of the dry season, right up to grass-roots by the time the wet season is well advanced. Leaching also plays an important part in the final distribution of the uranium.

Laterite may, however, have been formed over actual sulphide deposits and self-potential surveys have been used to detect such deposits. In one place in the Rum Jungle district, diamond drilling proved the existence of sulphide ore suggested by a self-potential survey.

EXPLORATION TECHNIQUES

Ordinary prospecting with geiger counters, especially in the vicinity of known deposits of other metals, is still the main basis of exploration and has given important results. In this type of work geologists come after the prospectors, assess possibilities and work out testing campaigns. Supplementary to this, however, is the systematic coverage of the province in the course of which geologists and geophysicists attempt to find deposits, and also to provide a basis upon which further prospecting by others may be undertaken.

Geological Mapping.—The province has been covered by air photography mostly on a scale of 1 : 30,000. The area around Rum Jungle itself has been re-photographed at 1 : 15,000 and some outlying districts have been flown at only 1 : 50,000.

Accurate topographic maps are available at 1 inch to 1 mile of limited areas only, but controlled photo-mosaics have been compiled as a stop-gap and the geology plotted on these or on tracings from them. Accurate planimetric maps of the whole province on a scale of 1 inch to 1 mile, based on slotted template assembly, are scheduled for preparation by the National Mapping Section, Department of the Interior.

Field work is carried out with the aid of landrovers and jeeps. Very few roads exist but the country is generally of the open savannah type and it is possible to drive almost anywhere over large parts of the province.

Geological maps are first compiled at the scale of the photographs and are reproduced at 1 inch to 1 mile to correspond with the sub-divisions of the National 1-mile military grid. Fairly detailed knowledge of structure and stratigraphy is absolutely essential for intelligent interpretation of radioactive anomalies, and for planning exploration and development in promising areas. The province was previously unmapped geologically except on a very broad reconnaissance basis and efforts are now being concentrated on regional geological mapping to overcome this deficiency.

In the mineralized areas it is commonly found that particular beds are im-

portant for ore, and in these places air photographs may be enlarged up to a scale of 1 inch to 400 feet for the purpose of detailed mapping. Prospects when located are mapped in detail by a plane table on scales of 200, 100 or 40 feet to the inch.

Airborne Scintillometer Surveys.—Airborne scintillometer surveys are carried out in a Dakota (DC3) aircraft using a Chalk River scintillometer type 190R, mark 2, developed by the Canadian Atomic Energy Commission. Flight lines are 1,000 feet apart and the plane is flown as far as possible at a constant height of 500 feet above ground surface. These surveys are being extended systematically throughout the known uranium province. The position of the plane in flight is maintained by the use of shoran apparatus. Two ground beacons are established at high points giving an uninterrupted "view" over the area being flown. The shoran co-ordinates are also used in plotting the results. Radioactive anomalies shown by the scintillometer are plotted as first, second and third order anomalies.

In some areas, anomalies are extremely numerous but ground investigation has shown that most of these do not correspond to ore deposits. Common causes of anomalies are small hillocks of radioactive granite or exposures of granite in areas that are mostly soil covered, ridges of slightly radioactive sediments, and beds of laterite. On the other hand, much leached sulfide lodes, although of economic importance, may not show up from the air as large anomalies because of the extensive leaching of the uranium from the surface. However, when the various features giving rise to the anomalous activity detected from the air have been classified geologically and correlated with the geological mapping, a sound appreciation is obtained of the distribution of radioactivity and the individual anomalies can be readily assessed. Each anomaly is plotted on photo-mosaics and air photographs, and is located on the ground by geologists and geophysicists with portable or vehicle-borne geiger equipment. A preliminary report on a set form is prepared giving the assessment of the cause of radioactivity and the recommendation for further work, if any is considered necessary.

An airborne magnetometer is flown with the scintillometer and this provides assistance in the geological interpretation of soil-covered areas where some beds, particularly in the vicinity of Rum Jungle itself, have been shown to be markedly magnetic. In addition, of course, a permanent record of the distribution of magnetism is obtained.

The aircraft used up to the present was originally designed for aeromagnetic surveys and was demagnetized for this purpose. The scintillometer was merely added to the equipment when the aircraft was diverted to airborne scintillometer work.

Ground Radiometric Surveys.—To aid in the rapid detection on the ground of radioactivity indicated by airborne surveys, batteries of geiger tubes, connected to a drum recorder, are mounted in a landrover or jeep. This equipment enables the sources of the radioactive anomalies to be tracked down very quickly and is also useful for reconnaissance work.

Scintillometer and geiger counters are used in the normal way for the systematic gridding of radioactive areas. The results are plotted as radiometric

contours either in terms of background or counts per minute and the results are combined with the geological plans of the area and the assay results obtained.

Self-Potential, Magnetic, and Electro-Magnetic Surveys.—Self-potential surveys have proved of value in detecting the presence of sulfide bodies underneath soil and laterite cover. These surveys are inexpensive and can be carried out fairly rapidly. They are particularly useful in laterite-covered areas where it is difficult to determine from surface information whether a radioactive anomaly may be due to the presence of an underlying sulfide body or simply to a slight relative concentration in laterite of uranium leached from the underlying formations with a very low disseminated uranium content. It is usual practice, therefore, to run a few self-potential traverses across all anomalous areas that are being investigated.

No orebodies so far found have special magnetic properties but magnetic surveys have helped to show the position of certain key formations. Electromagnetic surveys have been used to help confirm self-potential results.

Geochemistry.—As mentioned above, one of the problems of the district is to interpret accurately the meaning of the various types of radioactive leached outcrops. As an aid to this, residual soils and crushed rock have been tested systematically in some areas for the presence of copper and lead especially, and also for cobalt which has been found in one or two places. The dithizone technique is the one that has mostly been applied, and this has been supplemented by micro-chemical methods in some cases. Samples are tested in field laboratories set up in geological camps and the aim of the work has been to obtain quickly a plan showing qualitatively the distribution of one or two metals. Copper may be found where very inconspicuous casts after sulfides are now visible; alternatively, total absence of copper in leached outcrops, combined with other information, helps in places to determine whether any further work should be done on a particular deposit.

Costeaning.—Many areas where radioactive anomalies exist are completely covered, or almost completely covered, by soil and laterite. In some cases, moreover, radioactivity increases noticeably a few feet below the surface. To gain any assessment of these deposits a rapid means of surface trenching is necessary and this is usually carried out by means of a bulldozer, although sinking of pits and costeans by hand has to be resorted to at times.

It is often necessary to make tracts and roads to open up areas of interest and to level drill-sites, so the bulldozer finds a variety of uses in radioactive exploration.

The Bureau is considering the purchase of other equipment for trench digging.

Diamond Drilling.—Light diamond drills, the main components of which could be carried by two men, were used in the early part of the investigation, especially where the sulfide zone is shallow. These machines give only a $\frac{3}{4}$-inch core, and core recovery, especially in the weathered graphitic schists, was poor. Most of the information from these shallow holes was obtained from the sludges which were systematically collected and dried, the sludges from each 5 feet of sinking being kept separate. The results so obtained were

found in most cases to check out fairly well wherever underground exploration was undertaken in the same area, except in the case of one underground horizontal diamond hole at Rum Jungle. This passed through high grade ore in the first part of the hole which then contaminated some of the deeper parts of the hole.

The core and sludge information was supplemented by the use of geiger probes and generally good confirmation was obtained. This was so even in the hole mentioned above in which, apparently, some uranium from the high-grade portion of the hole had been carried along and lodged in cracks, so that a false high reading of the geiger probe was also obtained where subsequent crosscutting revealed no uranium.

The use of the light drills has been almost completely abandoned and present practice is to use heavier drills and to obtain larger diameter cores. In addition to the obvious purpose of determining the presence, grade and thickness of orebodies in depth, some of the drilling is designed primarily to determine the type of primary mineralization underlying the various kinds of leached outcrops, especially where these are of a type of which no previous experience has been gained. Once this information is available for particular deposits useful generalizations can be made for other untested deposits that show similar characteristics.

Bureau of Mineral Resources, Geology and Geophysics,
Commonwealth of Australia,
Canberra City,
March 24, 1954

REFERENCES

1. Noakes, L. C., 1948, A geological reconnaissance of the Katherine-Darwin Region, N. T.: Bur. Min. Res. Australia, Bull. 16, p. 64.
2. Gross, W. H., 1952, Radioactivity as a guide to ore: Econ. Geol., vol. 47, p. 722–742.
3. Sullivan, C. J., and Matheson, R. S., 1952, Uranium-copper deposits, Rum Jungle, Australia: Econ. Geol., vol. 47, p. 751–758.

PETROGRAPHIC EXAMINATION OF WASHED, SCREENED AND CRUSHED SAMPLES OF COAL FROM THE SYDNEY AND ST. ROSE COALFIELDS, NOVA SCOTIA[1]

P. A. HACQUEBARD AND K. C. LAHIRI

CONTENTS

	PAGE
Abstract	837
Introduction	838
Outline of procedure, techniques and standards for petrographic analyses of ground coal	843
Examination of washed coal from Emery seam of Dominion No. 24 colliery, Sydney coalfield	846
Examination of screened and crushed coal from Harbour seam of Florence colliery, Sydney coalfield	848
Examination of screened and crushed coal from No. 5 seam, St. Rose coalfield	851
Conclusions	861
Acknowledgments	861
Bibliography	862

ABSTRACT

The coal seams of the Sydney coalfield are in several ways extraordinary, since no great differences occur either in rank or petrographic composition. Over a stratigraphic interval of 3,800 feet the volatile matter content varies between 36 and 40 percent (mineral matter free). All 12 seams, with the exception of one, may be classed as very bright coal containing between 73 and 84 percent vitrain, plus bright clarain. However, each seam contains dull coal horizons high in opaque matter and/or exinite. Concentration of these dull parts by washing, screening and crushing was the objective of this study. Coals were examined from the Emery and Harbour seams of the Sydney coalfield, and from No. 5 seam of the St. Rose field.

The petrographic analyses were carried out with an integrating stage, using polished specimens of ground coal, mounted in lucite. Accuracy tests on this method were highly satisfactory.

Results obtained are: 1. Washed coal is lower in opaque matter than non-washed coal, since opaque matter together with shaly impurities concentrates in the fractions of higher density. 2. Concentration of opaque matter by screening alone depends on the amount and distribution of this material in the seam. Fusain is always higher in the finest fraction. 3. A notable concentration of dull coal is obtained by pounding and subsequent screening. Grinding instead of pounding does not give results. Only by taking advantage of the natural differences in strength of the coal components can concentrations be obtained.

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INTRODUCTION

It has long since been realized that coal is a heterogeneous substance, composed of different units that can readily be observed as banded ingredients. These banded ingredients, called vitrain, clarain, durain and fusain, have different chemical and physical properties, and accordingly behave differently on carbonization. Their swelling properties, agglutinating values, gas and tar productions, etc., vary widely, and are related to the constituents or macerals that they contain. The macerals originated from the plant debris that contributed to the formation of coal. They can only be observed through the microscope, and carry names, such as vitrinite, exinite, or micrinite. The banded ingredients and the macerals contained in them vary considerably in

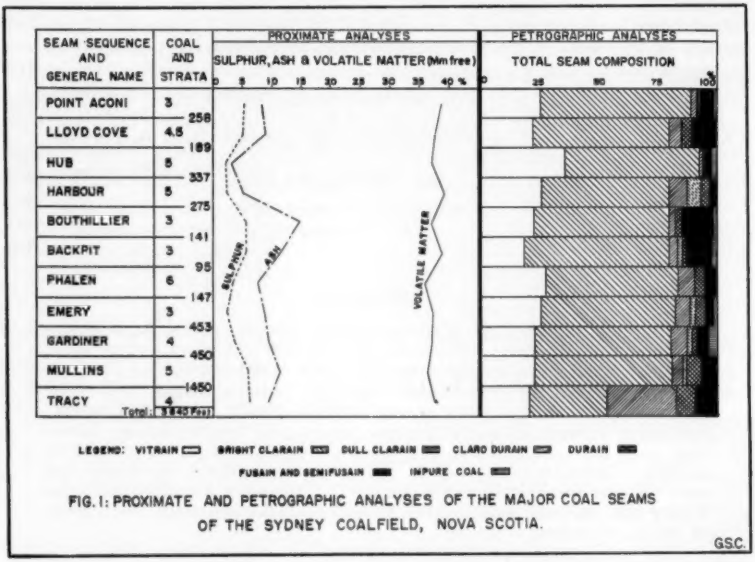

FIG. 1: PROXIMATE AND PETROGRAPHIC ANALYSES OF THE MAJOR COAL SEAMS OF THE SYDNEY COALFIELD, NOVA SCOTIA.

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their distribution throughout the section of a coal seam. These variations, as a rule, greatly exceed the differences that occur between the total seam composition of two separate seams. This is particularly so in the Sydney coalfield, where the total seam composition of the various seams, with the exception of one, is quite similar (Fig. 1).

Added to this is the fact that rank variation within the Sydney coalfield is so slight that it hardly affects the seams in a different manner. Over a stratigraphic interval of 3,840 feet the volatile matter content (mineral matter free) of the 11 major seams lies between 36 and 40 percent (Fig. 1 and Table I). On the other hand, the volatile matter content of vitrain and fusain from the same seam may vary as much as 23.61 percent. In the Tracy seam, for in-

TABLE I

COMPARISON OF PROXIMATE ANALYSES OF THE COAL SEAMS IN THE SYDNEY COALFIELD, CAPE BRETON, N. S.
(Compiled from analyses made by DOSCO Chemical Laboratory, Glace Bay, N. S.)

Seam sequence and General name	Sydney Mines District						
	Coal and strata	Proximate analyses					Number of analyses
		Dry basis				Mm. free	
		F.C.	V.M.	Ash	Sulph.	V.M.	
I Point Aconi	3.5′ 235′	54.64	37.01	8.35	5.58	38.80	2
II Lloyd Cove	5′ 185′	55.00	35.96	9.04	5.27	37.93	17
III Hub	6′ 310′						
IV Harbour	5′ 295′	56.55	38.95	4.50	2.00	40.18	113
V Bouthillier	3′ 110′	51.77	33.35	14.88	5.71	37.00	6
VI Backpit	3′ 80′	52.20	36.27	11.53	6.21	39.06	18
VII Phalen	5′ 80′	53.58	35.12	11.30	5.70	37.73	17
VIII Stony	3′ 110′						
IX Emery	2′ 525′	52.22	34.09	13.69	4.40	36.51	4
X Gardiner	2′ 400′						
XI Mullins	5′	55.44	34.25	10.31	6.00	36.25	2
XII Tracy	—						

TABLE I—*Continued*

Seam sequence and General name	New Waterford District							Glace Bay District						
	Coal and strata	Proximate analyses					Number of analyses	Coal and strata	Proximate analyses					Number of analyses
		Dry basis				Mm. free			Dry basis				Mm. free	
		F.C.	V.M.	Ash	Sulph.	V.M.			F.C.	V.M.	Ash	Sulph.	V.M.	
I Point Aconi	3′ 280′							—						
II Lloyd Cove	4′ 192′	53.87	34.49	11.64	6.32	36.96	2	— 100′						
III Hub	5.5′ 335′	54.63	33.32	12.05	3.18	36.46	2	9′ 365′	60.18	36.74	3.08	2.22	37.31	33
IV Harbour	5′ 275′	57.29	37.60	5.11	2.21	38.92	117	6′ 255′	56.50	37.69	5.81	3.18	39.08	115
V Bouthillier	3′ 82′	47.80	34.20	18.00	6.47	39.18	1	3′ 90′	54.50	34.46	11.00	4.69	37.06	1
VI Backpit	4′ 100′	51.38	35.50	13.12	5.59	38.92	2	3′ 105′	52.56	35.63	11.81	4.81	38.72	6
VII Phalen	6′	57.98	34.70	7.32	2.78	36.45	108	7′	58.45	34.02	7.53	3.28	35.65	318
VIII Stony	— 110′							— 140′						
IX Emery	2′ 540′							4′ 395′	56.44	35.03	8.53	2.69	37.25	142
X Gardiner	0–4′ 400′							4′ 550′	55.72	34.63	9.65	3.93	36.93	34
XI Mullins	5′	54.60	33.96	11.44	5.90	36.35	4	— 1450′						
XII Tracy	—							4′ Port Morien District	55.22	35.30	9.48	6.20	37.12	1

TABLE II

PROXIMATE ANALYSES OF VITRAIN AND FUSAIN SAMPLES TAKEN FROM THE MAJOR COAL SEAMS OF THE SYDNEY AND ST. ROSE COALFIELDS, C. B., N. S.*

Seam sequence and General name	Number and location of sample (District)	Vitrain					Fusain				
		Proximate analyses					Proximate analyses				
		Dry basis				Mm. free	Dry basis				Mm. free
		F.C.	V.M.	Ash	Sulph.	V.M.	F.C.	V.M.	Ash	Sulph.	V.M.
I Point Aconi	I— 1 Sydney Mines	57.40	38.30	4.30	1.99	39.84	59.89	23.26	16.85	10.38	23.34
II Lloyd Cove	II— 1 Sydney Mines	60.65	37.70	1.65	2.46	37.76	63.83	22.80	13.37	4.26	24.07
III Hub	III— 1 Glace Bay	58.45	38.30	3.25	2.54	38.94	65.40	25.60	9.00	4.08	26.41
IV Harbour	IV— 3 Sydney Mines	62.82	36.28	0.90	0.84	36.39	76.80	18.75	4.45	0.86	19.06
V Bouthillier	V— 3 Sydney Mines	58.16	37.80	4.04	2.59	38.68	60.35	23.25	16.40	10.21	23.29
VI Backpit	VI—16 New Waterford	59.84	37.00	3.16	2.31	37.58	49.49	21.25	29.26	5.16	25.68
VII Phalen	VII— 2 New Waterford	64.06	33.22	2.72	2.28	32.45	53.02	21.18	25.80	5.28	24.55
IX Emery	IX— 3 Glace Bay	63.83	34.60	1.57	1.29	34.80	79.91	13.05	7.04	0.82	13.22
X Gardiner	X— 2 Glace Bay	63.98	33.50	2.52	2.18	33.75	68.25	19.77	11.98	3.96	20.30
XI Mullins	XI— 1 New Waterford	61.71	35.34	2.95	2.36	35.77	60.93	16.35	22.72	9.16	15.40
XII Tracy	XII— 1 Port Morien	60.88	36.82	2.30	3.77	36.81	64.72	13.35	22.20	4.71	13.20
No. 5 Seam	SR— 1 St. Rose	54.92	39.10	5.98	4.36	40.51	49.50	23.30	27.20	13.00	25.08

* These analyses were made by Mr. M. Bates, Analytical Engineer, Chemical Laboratory of DOSCO, Glace Bay, N. S.

stance, the volatile matter content of vitrain is 36.81 percent, while that of fusain is 13.20 percent. Similar differences occur in the other seams, as may be seen from Table II.

Concentration of banded ingredients from individual seams is therefore of much importance to the Sydney coalfield. Its practical significance may also be concluded from Figure 2, showing the petrographic composition of coking coals from various coal areas. The Sydney coking coal may be classed as an extremely bright coal, containing only 10 percent dull coal components, and 7 percent total opaque matter. These low figures are in sharp contrast with those of other coking coals, and more than likely are partly responsible for the rather weak nature of Sydney metallurgical coke, which has an ASTM stability factor that lies between 23 and 27 (tumbler test). The 1½ inch shatter index of Sydney cokes is around 75, while the average index of Yorkshire

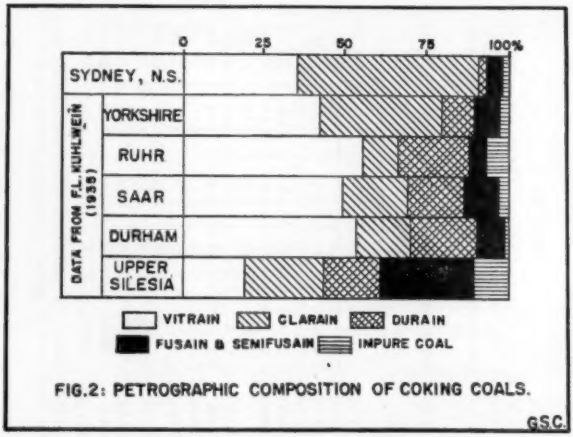

FIG.2: PETROGRAPHIC COMPOSITION OF COKING COALS.

cokes is 82.55 (2).[2] The coking coals from both areas contain about an equal amount of volatile matter, but the Yorkshire coals have 18 percent dull coal components, against 10 percent in the Sydney coals.

That the strength of coke can be raised markedly by addition of dull coal, high in opaque matter, has been shown by investigations carried out in Germany by F. L. Kühlwein, C. Abramski, H. Hoffmann and others (6–11). Blending tests on Saar coking coals, with a volatile matter content of 39 percent, gave the following results. An increase in shatter index from 62 to 83 (percent retained on a 30 mm screen, after 4 drops) was obtained on coke produced by blending 20 percent dull coal with 80 percent coking coal. The dull coal contained 44 percent durain, which had 33 percent opaque matter. Similar results were noted when nut coal, with 24 percent dull coal components, was added to slack coal that contained only 14 percent. In this in-

[2] Numbers in parentheses refer to References at end of paper.

stance, both nut and slack coal were from the same seam, with a volatile matter content of 26 percent. However, the authors point out that crushing of the nut coal to below 1 mm is essential; otherwise no beneficial effect of the opaque components to the strength of the coke is obtained. This effect is related to the more or less inert reaction of opaque matter during carbonization. In coke these inert parts may be compared with steel in reinforced concrete.

The present study was made to determine if gravity separations would influence the petrographic composition, and if by means of screening and crushing, concentrations of dull coal could be obtained. The objective being, the preparation of coals of a different composition than those that are now available.

Petrographic analyses, on both macerals and banded ingredients, were carried out on samples from the Sydney and St. Rose coalfields. The latter was included, because the No. 5 seam of this field contains a considerable amount of dull coal, which is higher in opaque matter than any from the Sydney field.

OUTLINE OF PROCEDURE, TECHNIQUES AND STANDARDS FOR PETROGRAPHIC ANALYSES OF GROUND COAL

Petrographic analyses of washed and screened coal require a method by which it is possible to make quantitative determinations of macerals and banded ingredients on ground coal. The reflected light technique, with polished surfaces, proved most adaptable for this purpose. A representative sample of 3 to 4 grams, of the coal to be analysed, is ground to below 0.5 mm. This coal is embedded in lucite (or some other bond) and the percentages of the different components are recorded with the aid of a Leitz integrating stage, attached to a reflected light microscope. The method was introduced by Kühlwein in 1934, and has been described in detail by Hacquebard (5).

Kühlwein used the integrating stage to determine the percentage of banded ingredients only. His figures on total seam composition thus obtained compare closely with quantitative measurements carried out on a complete series of polished sections (Table III).

From Table III it is evident that the I.S. method for quantitative determinations of banded ingredients is sufficiently accurate. The microscopic procedure is also less tedious than is the case with other methods, and above all it can be carried out quite rapidly. However, the preparation of a representative sample is essential for reliable results. This is done by the standard coning and quartering method of the bulk sample, and subsequent use of the sample splitter for the smaller quantities of which the lucite pellets are made. Bulk samples of 300 to 400 lbs. were used in this report, and of each screened and crushed fraction four lucite pellets, representing four quarters, were prepared and analysed. The composition given of each fraction is therefore an average of four different analyses.

The determination of the type of banded ingredient from small particles of coal, as present in the lucite pellets, requires a strict adherence to a uniform classification. The rules laid down for this in the German Atlas for Applied

Coal Petrography (1) were followed as closely as possible. However, it was found that in many cases, specific standards had to be set, in order to obtain a uniform classification by different microscopists. As may readily be understood, it is not always possible to determine if certain small particles are derived from a bright clarain, a dull clarain, or sometimes even a durain band. For this purpose Figures 9 and 10 have been compiled, which show, with a

TABLE III

COMPARISON OF BANDED INGREDIENT DETERMINATIONS BY INTEGRATING STAGE METHOD ON GROUND COAL (I.S.), AND COMPLETE SERIES OF POLISHED SECTIONS (P.S.) (AFTER KÜHLWEIN, 9, P. 548)*

No. of column samples...	No. 1		No. 2		No. 3		No. 4	
Type of examination.....	I.S.	P.S.	I.S.	P.S.	I.S.	P.S.	I.S.	P.S.
Vitrain	46	44	35	34	41	38	34	32%
Clarain	31	29	38	39	36	38	42	43%
Durain	12	13	16	14	11	13	14	14%
Semifusain	4	4	3	3	4	4	3	3%
Fusain	6	9	7	9	7	6	6	7%
Carbonaceous shale	1	1	1	1	1	1	1	1%

* Columnar section of Hagen seam-Ruhr flame coal.

series of photomicrographs, the classification that has been used for this investigation. The degree of accuracy that was obtained by following these standards is shown in Table IV. Four different examiners analysed four lucite pellets of the four quarters that were prepared of screensize -4 to $+2$ inches of the St. Rose No. 5 seam. The data presented in Table IV show

TABLE IV

ACCURACY TEST ON INTEGRATING STAGE METHOD FOR BANDED INGREDIENTS*

Quarter No.....	1	2	3	4	Average
Vitrain	26	27	23	26	25%
Bright clarain	37	39	40	38	38%
Dull clarain	15	13	12	13	14%
Durain	16	15	16	17	16%
Fusain	3	5	4	3	4%
Semifusain	3	1	5	3	3%
Examiner:	A	B	C	D	

* St. Rose No. 5 seam-screensize -4 to $+2''$.

minor variations, which are related foremost to the fact that four different quarters were analysed. It is felt that the average figures of the four quarters give reliable percentages of the composition of the original sample.

The quantitative determination of macerals has also been carried out with lucite pellets and integrating stage. The procedure followed has been described by Hacquebard (5). A comparison between this method and the

TABLE V

COMPARISON OF MACERAL DETERMINATIONS BY INTEGRATING STAGE METHOD ON GROUND COAL, AND COMPLETE SERIES OF POLISHED SECTIONS*

Petrographic interval		Type of microscopic examination	Petrographic composition—percent by volume				
Number	Thickness (inches)		Vitrinite	Exinite	Opaque matter	Shale	Pyrite
I	2.6	5 polished sections	94	4	0	1	1
		one lucite pellet	94	4	0	1	1
II	4.1	8 polished sections	87	9	4	0	0
		one lucite pellet	87	8	4	0	1
III	6.4	12 polished sections	89	8	2	0	1
		one lucite pellet	86	9	3	1	1
IV	9.4	17 polished sections	87	6	6	0	1
		one lucite pellet	86	6	5	1	2
V	4.6	8 polished sections	65	7	12	14	2
		one lucite pellet	71	5	11	11	2
VI	6.9	14 polished sections	84	8	3	0	5
		one lucite pellet	86	6	4	0	4

* Columnar section of Emery seam, Sample IX-3, from Dominion No. 11 colliery, Sydney coalfield.

one using a complete series of polished sections is shown in Table V. Even more so than with the determination of banded ingredients, a maceral analysis with the aid of a complete series of polished sections is a very tedious and lengthy procedure. Table V shows, that the differences that occur between the analysis of one lucite pellet and as many as 17 polished sections are only minor. Both a lucite pellet of ground coal and one polished section of about 1½ cm thickness can be run in one hour. Consequently, to complete interval

TABLE VI

VARIATIONS IN MACERAL COMPOSITION OF FOUR QUARTERS OF THE SAME SAMPLE*

Quarter No.....	1	2	3	4	Average
Vitrinite	75	74	72	75	74%
Exinite	11	12	13	12	12%
Micrinite	6	7	7	7	7%
Fusinite	1	2	2	1	1%
Shale	3	2	3	2	3%
Pyrite	4	3	3	3	3%

* Harbour seam, Florence colliery, Sydney coalfield. Size −4 to +2", crushed to ¼" and screened above 3.4 mm.

IV with the polished section method requires 17 hours, against one hour with a lucite pellet. Furthermore, it is believed that at least for a maceral determination, the lucite pellet method is more reliable, since coal particles cut at different angles to the bedding plane are examined. This is not the case with a polished section, where each face is cut at right angles to the bedding plane. The lucite pellet method is therefore recommended not only for maceral determinations of coals obtained by washing, screening, or run of mine, but also for columnar section studies of different seams.

The variations that occur between the maceral determinations of four quarters from the same sample are given in Table VI. Throughout the report, with the exception of the washed coal from the Emery seam, the average figures thus obtained were accepted as being the composition of the whole.

EXAMINATION OF WASHED COAL FROM EMERY SEAM OF DOMINION NO. 24 COLLIERY, SYDNEY COALFIELD

A series of washing tests were carried out by the Chemical Laboratory of the Dominion Coal Company Ltd. at Glace Bay, on coals from the various collieries now in operation by this company in the Sydney coalfield. Through

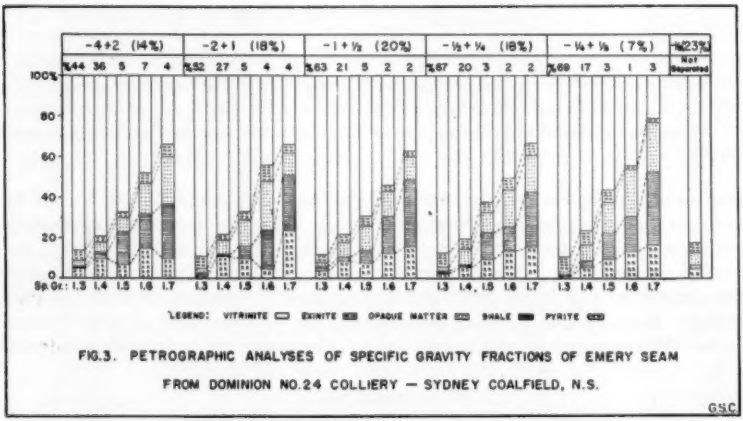

FIG.3. PETROGRAPHIC ANALYSES OF SPECIFIC GRAVITY FRACTIONS OF EMERY SEAM FROM DOMINION NO.24 COLLIERY — SYDNEY COALFIELD, N.S.

the kind cooperation of Mr. M. Bates, the chemical engineer of DOSCO, samples of different specific gravity fractions from the Emery seam were obtained for a petrographic analysis. The tests were carried out at 1.30, 1.40, 1.50, 1.60, and 1.70 specific gravity, and 26 samples from coal floating at these densities, of the following screensizes: -4 to $+2$; -2 to $+1$; 1 to $+\frac{1}{2}$; $-\frac{1}{2}$ to $+\frac{1}{4}$; $-\frac{1}{4}$ to $+\frac{1}{8}$; and $-\frac{1}{8}$ inch, were examined. The $-\frac{1}{8}$ inch screensize was not separated by gravity.

The results are illustrated in Figure 3. The composition of the total sample, before washing and screening, is as follows: vitrinite 79 percent; exinite

5 percent; opaque matter 5 percent; shale 5 percent; pyrite 6 percent (by weight). Figure 3 shows that gravity separation of different screensizes materially affects the petrographic composition, but although sizable concentrations occur, the amounts of these per total sample are extremely low. The only exception is vitrinite, which may be concentrated to a maximum of 87 percent in 59 percent of the total sample. Opaque matter can be concentrated to a maximum of 24 percent in only 0.4 percent of the total sample. This is not surprising, in view of the very low figure of 5 percent opaque matter in the original sample. Only when present in greater quantities can worthwhile concentrations be expected.

The best results of the gravity separation were obtained in the finest screen fraction. In the $-\frac{1}{4}$ to $+\frac{1}{8}$ inch size the components are concentrated in a regular pattern which is in accordance with their individual specific gravities. Vitrinite and exinite, with a specific gravity of 1.3 and 1.2 respectively, show a gradual decline in the fractions of higher density. Opaque matter, shale and pyrite, with specific gravities of 1.4, 2 and 5, increase fairly regularly from

TABLE VII

SPECIFIC GRAVITY FRACTIONS OF SCREENSIZES -4 TO $+\frac{1}{8}$ INCH COMBINED (BY CALCULATION)*

% Total sample of -4 to $+\frac{1}{8}''$	59	25	4	3	3
Vitrinite	87	78	66	48	33%
Exinite	6	4	5	5	4%
Opaque matter	2	7	10	17	16%
Shale	2	2	10	17	28%
Pyrite	3	9	9	13	19%
Specific gravity	1.30	1.40	1.50	1.60	1.70

* Emery seam, Dominion No. 24 colliery, Sydney coalfield.

the lower to the higher gravity fractions (Figs. 3, 11). A similar, but less regular pattern, occurs in screensize $-\frac{1}{2}$ to $+\frac{1}{4}$ inch. In the larger screensizes the components, with the exception of vitrinite, are more randomly distributed through the different gravity fractions. The reason for this is that in the larger blocks the densities of shale and pyrite, both present in varying proportions, counteract those of the coal macerals.

A composite of the screensizes from -4 to $+\frac{1}{8}$ inch, arrived at by calculation (Table VII), shows that the increase in shale in the fractions of higher densities is accompanied by an increase in opaque matter. This is caused by the fact that in the Emery seam the bulk of the opaque matter occurs in one horizon composed of bands of impure coal or carbonaceous shale (Table V, Fig. 11: 5). In these bands shale and opaque matter are so intimately mixed, that separation of one from the other is next to impossible. Furthermore, the remainder of the coal is so extremely bright that a sizable concentration of opaque matter in the lighter fractions, which are low in shale, cannot be expected. Only 7 percent opaque matter is present in the 1.40 float of

screensizes − 4 to + ⅛ inch combined. The high figure of 9 percent pyrite that accompanies this is caused foremost by the larger screensizes (− 4 to + ½ inch), which contain 10 percent pyrite at 1.40 gravity, against 6 percent in the − ½ to + ⅛ inch sizes. A somewhat higher percentage of opaque matter at 1.40 float, with less pyrite, may be obtained by crushing the entire sample to below − ⅛ inch screensize, and also by including the − ⅛ inch size in the gravity separation.

The cumulative results on screensizes − 4 to + ⅛ inch combined are given in Table VIII. They show that commercial washing will produce a coal that is very high in vitrinite and extremely low in opaque matter. Washing therefore probably has an adverse effect on the strength of coke, because the inert components (opaque matter) are reduced and the swelling components (vitrinite) are increased. In connection with this it may be advisable to include the − ⅛ inch screensize with the washing, since it contains most of the fusain, which otherwise becomes lost.

TABLE VIII

CUMULATIVE RESULTS ON SPECIFIC GRAVITY SEPARATIONS OF SCREENSIZES −4 TO +⅛ INCH COMBINED (BY CALCULATION)*

% Total sample of −4" to +⅛"	59	84	88	91	94
Vitrinite	87	85	84	83	81%
Exinite	6	5	5	5	5%
Opaque matter	2	3	4	4	5%
Shale	2	2	2	3	4%
Pyrite	3	5	5	5	5%
Ash	3.83	5.70	6.37	7.19	8.14%
Sulphur	1.57	2.28	2.42	2.50	2.62%
Specific gravity	1.30	1.30–1.40	1.30–1.50	1.30–1.60	1.30–1.70

* Emery seam, Dominion No. 24 colliery, Sydney coalfield.

EXAMINATION OF SCREENED AND CRUSHED COAL FROM HARBOUR SEAM OF FLORENCE COLLIERY, SYDNEY COALFIELD

The Harbour seam is the most important seam of the Sydney coalfield; it is extensively mined and is, in general, of excellent quality. Ash and sulphur content, as a rule, are lower than in the other seams whereas the volatile matter content is somewhat higher (Table I).

The Harbour coal is a predominantly bright coal (Fig. 1), but contains, with the exception of the Tracy seam, more intervals with appreciable amounts of dull coal components than any other seam of the Sydney coalfield. Characteristic of the Harbour seam are several clarodurain bands, which are very high in exinite (mostly spore exines). In the Sydney Mines District, where the Florence colliery is located, the average seam composition is as follows: vitrain 25 percent; bright clarain 56 percent; dull clarain 5 percent; claro-

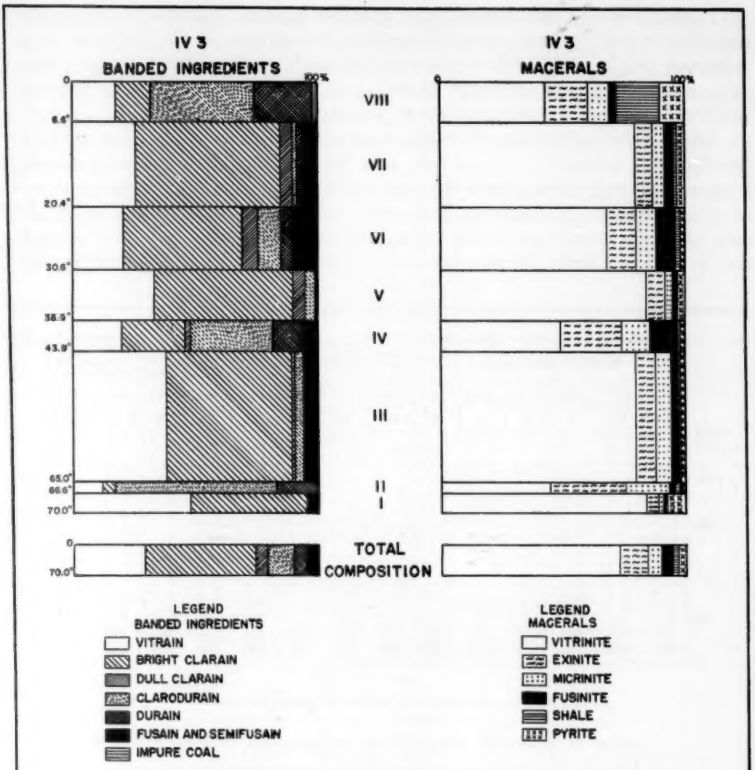

FIG.4: PETROGRAPHIC PERCENTAGE DIAGRAMS OF THE BANDED INGREDIENT AND MACERAL COMPOSITION OF THE HARBOUR SEAM IN FLORENCE COLLIERY, SYDNEY COALFIELD, NOVA SCOTIA.—

durain 7 percent; durain 4 percent; and fusain 3 percent (based on 7 column samples).[3]

The amounts in which banded ingredients and macerals are present in different intervals of the seam, are illustrated in the percentage diagrams of Figure 4. These diagrams were prepared of column sample IV-3, which may be considered as a representative petrographic section of the Harbour seam in the Florence colliery.

[3] Vitrain and fusain represent bands of 1 mm or more in thickness. Bright clarain contains less than 10 percent, dull clarain from 10 to 30 percent, and durain more than 30 percent opaque attritus. Clarodurain has less than 30 percent opaque attritus and less than 50 percent vitrinite (Hacquebard, 3).

Figure 4 shows that considerable variations in the distribution of banded ingredients and macerals occur throughout the section of the Harbour seam. Although bright coal (high in vitrinite) strongly predominates, certain intervals contain sufficient amounts of dull coal (high in exinite, micrinite and fusinite) to warrant concentration experiments.

These experiments were carried out on a 300 lb. run of mine sample from the Florence colliery. This sample was first screened into 6 sizes, ranging from -4 to $-\frac{1}{8}$ inch. Next the larger sizes of -4 to $+2$ inches and -4 to $+1$ inch were ground to $\frac{1}{4}$ inch, and then screened above and below 3.4 mm. Finally, pounding experiments were made on sizes -4 to $+1$ inch, and -4 to $+\frac{1}{4}$ inch, which were pounded until $\frac{1}{3}$ of their respective quanti-

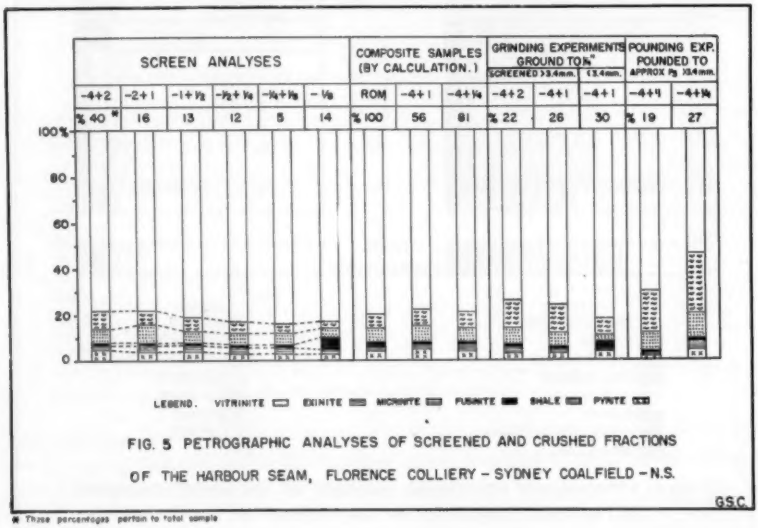

FIG. 5 PETROGRAPHIC ANALYSES OF SCREENED AND CRUSHED FRACTIONS OF THE HARBOUR SEAM, FLORENCE COLLIERY – SYDNEY COALFIELD – N.S.

GSC

* These percentages pertain to total sample

ties was retained above 3.4 mm screensize. The petrographic analyses were carried out for macerals only, and the results are illustrated in Figure 5.

The screen analyses showed minor, though significant differences. From the largest to the smallest screensizes the following variations were noted: vitrinite increased from 78 to 84 percent; exinite decreased from 8 to 3 percent; micrinite dropped from 8 to 4 percent; fusinite remained constant at 1 percent, until the $-\frac{1}{8}$ inch size was reached, where it increased to 5 percent; shale varied only from 2 to 3 percent; whereas pyrite dropped from 5 to 3 percent.

The grinding experiments carried out on the larger screensizes were made with the objective of further concentrating the macerals exinite and micrinite, which occur more abundantly in these sizes than in the smaller ones. The tests were only partially successful, and revealed that exinite may be increased

from 8 to 12 percent, but an increase of micrinite was not obtained. This may be explained by the fact that the grinding does not take full advantage of the natural differences in strength that exist between the coal components.

The results of the pounding experiments, however, were most encouraging. Exinite increased from 7 to 18 percent in the -4 to $+1$ inch size, and from 7 to 26 percent in the -4 to $+\frac{1}{4}$ inch size. Concentration of micrinite was less pronounced, and ranged from 7 to 8 percent, and from 6 to 11 percent, respectively. That these figures are not higher is due to the composition of the dull coal in the Harbour seam. This seam contains 7 percent clarodurain, against only 4 percent durain. The former consists almost entirely of spore exines, whereas the latter, according to its definition, must have more than 30

TABLE IX

RESULTS OF POUNDING EXPERIMENTS ON SCREENSIZES -4 TO $+1$ INCH AND -4 TO $+\frac{1}{4}$ INCH (POUNDED UNTIL $\frac{1}{4}$ IS RETAINED ABOVE 3.4 MM. SCREENSIZE) *

Screen size	Type of sample	Percent total sample	Proximate analyses (%)†				
			Moist.	V.M.	F.C.	Ash	Sulph.
-4 to $+1''$	original	56	1.3	37.0	56.0	5.7	1.3
	after pounding	19	1.3	39.1	55.4	4.2	1.3
-4 to $+\frac{1}{4}''$	original	81	1.5	38.3	56.1	4.1	1.6
	after pounding	27	1.2	44.1	46.2	8.5	1.8

Screen size	Type of sample	Percent total sample	Petrographic analyses (% by weight)					
			Vitrinite	Exinite	Micrinite	Fusinite	Shale	Pyrite
-4 to $+1''$	original	56	78	7	7	1	2	5
	after pounding	19	70	18	8	1	1	2
-4 to $+\frac{1}{4}''$	original	81	79	7	6	1	3	4
	after pounding	27	54	26	11	1	4	4

* Harbour seam, Florence colliery, Sydney coalfield.

† These data were kindly supplied by the Fuel Research Laboratories of the Mines Branch, Department of Mines and Technical Surveys.—Ottawa, Ont.

percent opaque attritus (micrinite plus fusinite). Added to this is the composition of dull clarain, which also contains a considerable amount of exinite but, as a rule, is fairly low in micrinite (Fig. 12).

That by pounding and subsequent screening a different coal has been prepared is substantiated by the proximate analyses that are given in Table IX. The increases in volatile matter content are undoubtedly caused by the concentrations of exinite.

EXAMINATION OF SCREENED AND CRUSHED COAL FROM NO. 5 SEAM, ST ROSE COALFIELD

The petrographic composition of the St. Rose No. 5 seam is entirely different from the Harbour seam of the Sydney coalfield. This may at once be

noticed from the total seam composition of the No. 5 seam, which was calculated from columnar section SR 1, described in detail in a previous publication (Hacquebard, 4). The following figures were obtained: vitrain 19 percent; bright clarain 23 percent; dull clarain 36 percent; clarodurain 2 percent; durain 17 percent; and fusain 3 percent. (See footnote 3.) This seam is further characterized by its uniform distribution of dull coal thoughout the

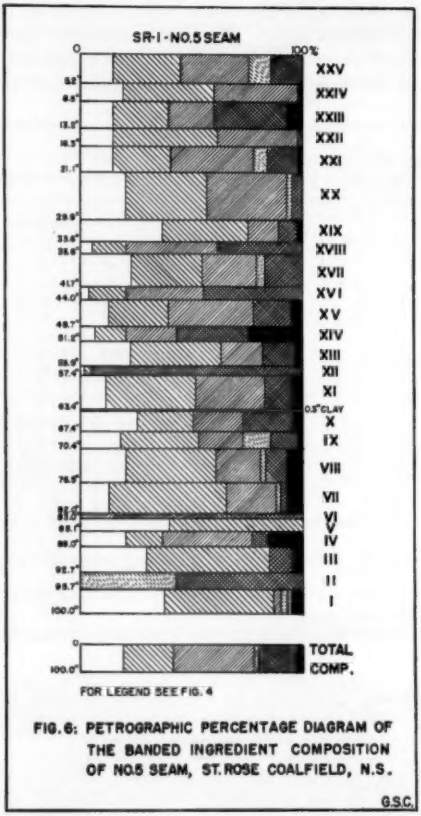

FIG. 6: PETROGRAPHIC PERCENTAGE DIAGRAM OF THE BANDED INGREDIENT COMPOSITION OF NO.5 SEAM, ST. ROSE COALFIELD, N.S.

G.S.C.

section of the seam (Fig. 6). This distribution is greatly unlike that of the Harbour seam, where the dull horizons are separated by very bright coal, containing much vitrinite (compare Fig. 4). Another striking difference is the maceral content of the dull coal components. In the No. 5 seam these components are low in exinite (only 5%), but high in opaque attritus (from 22 to 51%) (Fig. 9: 13; Fig. 10: 2, 10; Fig. 7).

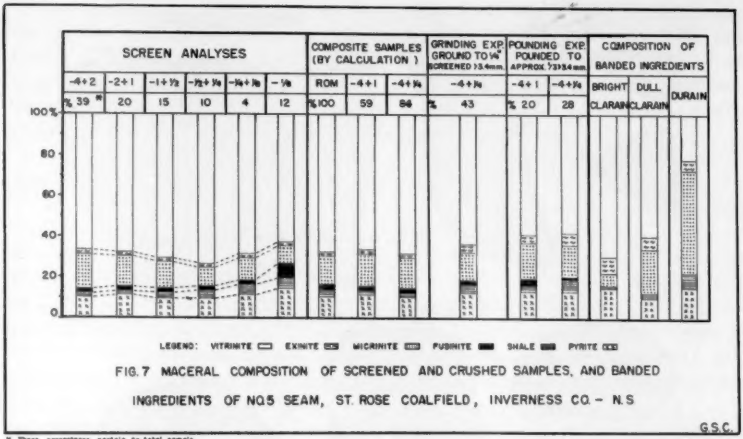

FIG. 7 MACERAL COMPOSITION OF SCREENED AND CRUSHED SAMPLES, AND BANDED INGREDIENTS OF NO.5 SEAM, ST. ROSE COALFIELD, INVERNESS CO. – N.S

G.S.C.

* These percentages pertain to total sample.

These differences also find expression in the proximate analyses of the No. 5 and Harbour seams. The former is somewhat lower in rank and, unfortunately, much higher in ash and sulphur than the latter. The analysis of the No. 5 seam gave the following figures: fixed carbon 50.85 percent; volatile matter 38.15 percent; ash 11 percent; and sulphur 7.0 percent.

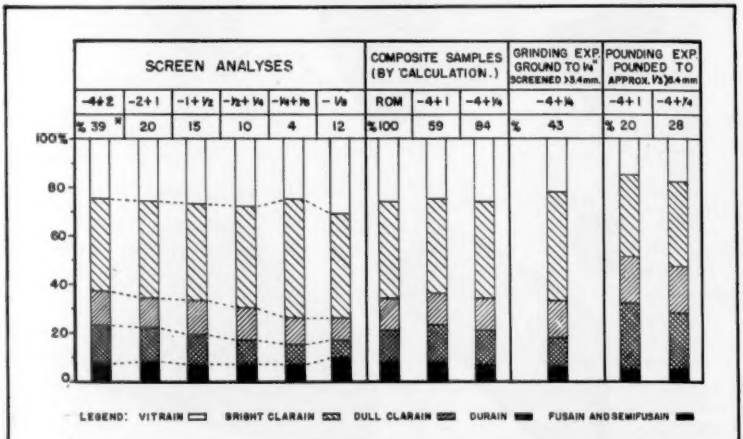

FIG. 8 PETROGRAPHIC ANALYSES OF SCREENED AND CRUSHED FRACTIONS OF NO.5 SEAM, ST ROSE COALFIELD, INVERNESS CO. – N.S.

G.S.C.

* These percentages pertain to total sample

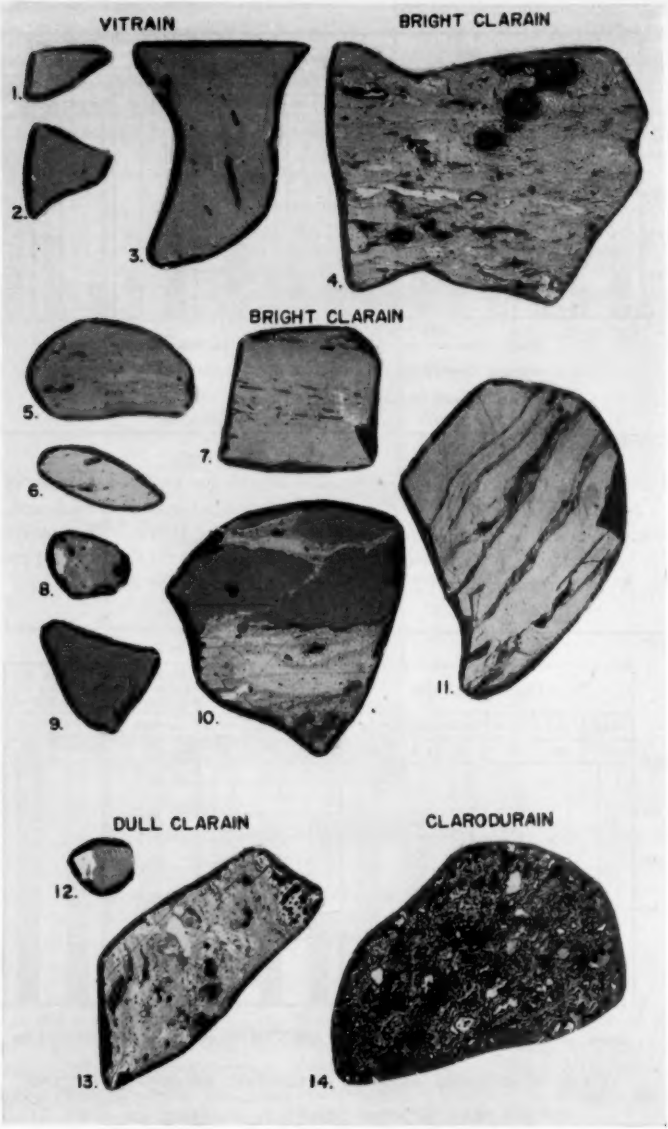

FIG. 9. Classification of banded ingredients from small particles of coal.[4]

[4] All pictures illustrated are from photographs taken by P. A. Hacquebard and M. S. Barss, Technician, Fuels Resources Division, Geological Survey of Canada.

Concentration experiments, similar to those on the Harbour seam, were carried out on a run of mine sample of the No. 5 seam. However, the uniform distribution of dull clarain and durain, both high in opaque matter, made it rather doubtful if equally good results could be obtained. This seam was chosen, nevertheless, because both its amount of dull coal and of opaque matter exceeds that of any seam in the Sydney coalfield.

The petrographic analyses, carried out on both macerals and banded ingredients gave the following results (Figs. 7 and 8).

In the different screensizes from − 4 to − ⅛ inch vitrinite varied between 74 and 63 percent, but not in a regular manner. The − ⅛ inch size had the lowest figure, whereas 74 percent was present in the − ½ to + ¼ inch size. In the Harbour seam (see page 850) vitrinite increased from 78 to 84 per cent in a regular fashion from the largest to the smallest screensizes. Exinite remained constant at 2 percent. Micrinite decreased fairly uniformly from 17 to 9 percent. Fusinite stayed constant at 2 percent, until it increased to 7 percent in the − ⅛ inch size. Shale showed an increase from 2 to 5 percent, and pyrite varied rather irregularly between 9 and 14 percent (Fig. 7).

As was the case with the Harbour coal, grinding to ¼ inch and subsequent screening at 3.4 mm hardly affected the petrographic composition. The coal retained above 3.4 mm screensize showed a drop of 5 percent in vitrinite, which was accompanied by a 2 percent increase in exinite, shale, and pyrite respectively, as compared to the original samples (size − 4 to + ¼ inch).

The pounding tests were also disappointing because a sizable increase in opaque matter (micrinite plus fusinite), which was the objective of this investigation, was not obtained. After pounding, opaque matter was concentrated

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Particles classed as one banded ingredient.

Vitrain

Small: 1, vitrinite only. × 120 [5]; 2, vitrinite with one or two small fragments of opaque attritus or exinite.

Larger: 3, vitrinite with one or two scattered microspores, cuticles or fragments of opaque attritus.

Bright Clarain

Small: 5, vitrinite with vague traces of resinous (?) matter; 6, vitrinite with one or two small spores, cuticles or fragments of opaque attritus; 8, vitrinite containing between 5 and 10% opaque attritus; 9, exinite only.

Larger: 4, particle containing more than 50% vitrinite, with exinite, and less than 10% opaque attritus; 7, particles composed of bands less than 100 microns: consider whole piece, in this case bright clarain; 10, vitrinite containing resinite; 11, vitrinite with several thin cuticles.

Dull Clarain

Small: 12, vitrinite containing between 10 and 30% opaque attritus.

Larger: 13, particle containing more than 50% vitrinite, with exinite and between 10 and 30% opaque attritus.

Clarodurain

14, particle containing less than 50% vitrinite and less than 30% opaque attritus (from Harbour seam, Florence colliery).

[5] All pictures illustrated on Figs. 9 and 10, except Fig. 9: 14, were taken from the St. Rose No. 5 seam.

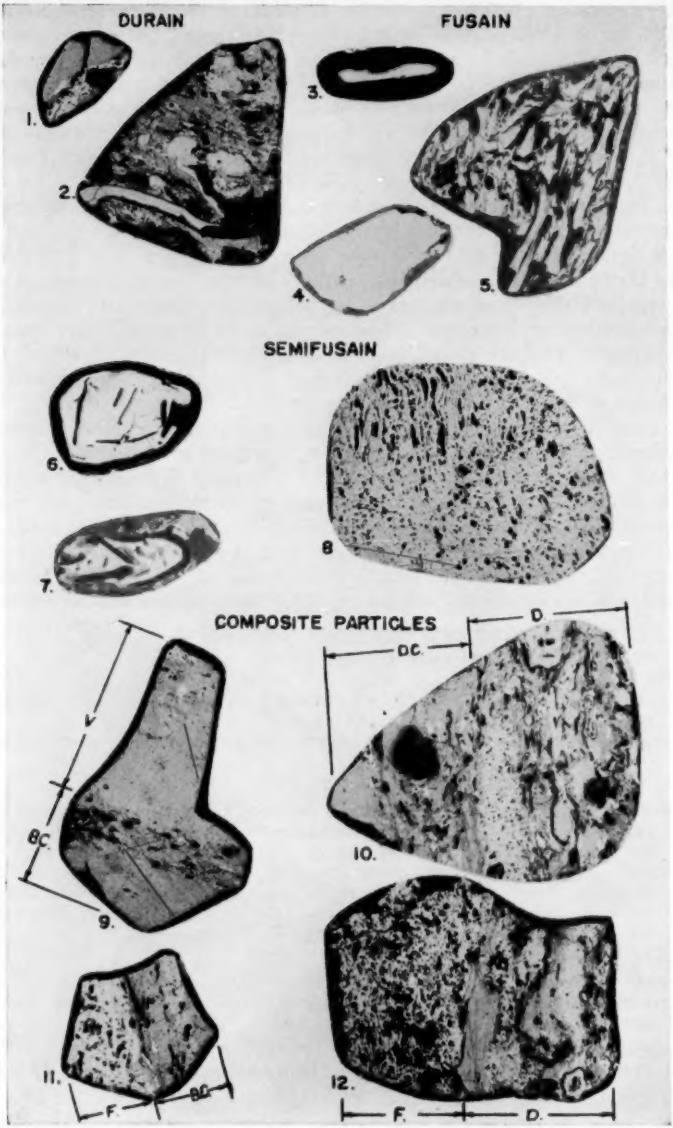

FIG. 10. Particles classed as one banded ingredient (continued).

from 18 to 21 percent in the − 4 to + 1 inch size, and remained constant at 17 percent in the − 4 to + ¼ inch size. In both cases, moreover, shale and pyrite increased by 1 and 4 percent, and by 2 and 3 percent respectively, in the two screensizes that were used.

The results of the banded ingredient analyses, illustrated in Figure 8, were quite different from those of the macerals. The banded ingredients were more regularly distributed through the different screensizes, and higher concentrations were obtained in the pounded samples.

The screen analyses showed the following variations between the largest and smallest screensizes. Vitrain increased from 25 to 31 percent. Bright clarain increased from 38 to 49 percent in the − ¼ to + ⅛ inch size, and then dropped to 43 percent in the − ⅛ inch size. Dull clarain showed a somewhat irregular decline from 14 to 9 percent. Durain decreased very regularly from 16 to 7 percent. Fusain remained practically constant at 4 percent, until the − ⅛ inch size was reached, where it increased to 8 percent. Semifusain stayed constant at 3 percent.

The grinding experiment, again, hardly affected the petrographic composition and therefore needs no further comments.

In contrast to opaque matter, which was only slightly affected by pounding, a sizable concentration of durain, and to a lesser degree of dull clarain, was obtained. Durain was concentrated from 15 to 27 percent in screensize

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Durain

Small: 1, vitrinite containing between 30 and 95% opaque attritus.
Larger: 2, particle containing more than 30% opaque attritus, and varying amounts of vitrinite and exinite.

Fusain

Small: 3, fusinite splinter; 4, particle containing more than 95% opaque attritus.
Larger: 5, fusain with cellular structure.

Semifusain

Small: 6, isolated sclerotioid; 7, sclerotioid plus a minor amount of other material.
Larger: 8, semifusain with cellular structure.

Composite Particles

Size rule: 1, for vitrain, bright and dull clarain, clarodurain and durain bands lift out when greater than 100 microns, and run the remainder as is; 2, (a) for fusain and semifusain bands present in vitrain, bright and dull clarain lift out when greater than 50 microns; (b) when present in clarodurain and durain lift out when greater than 100 microns.

9, particle composed of vitrain (V) and bright clarain (BC). The upper vitrain band is greater than 100 microns, but the lower vitrain being less than 100 microns is included with the overlying band, and together are classed as bright clarain; 10, particle composed of dull clarain (DC) and durain (D). Both are greater than 100 microns, but if one were less than 100 microns the particle would still be considered as two banded ingredients; 11, particle composed of fusain (F) and bright clarain (BC). The fusain is greater than 50 microns; 12, particle composed of fusain (F) and durain (D). The fusain is greater than 100 microns.

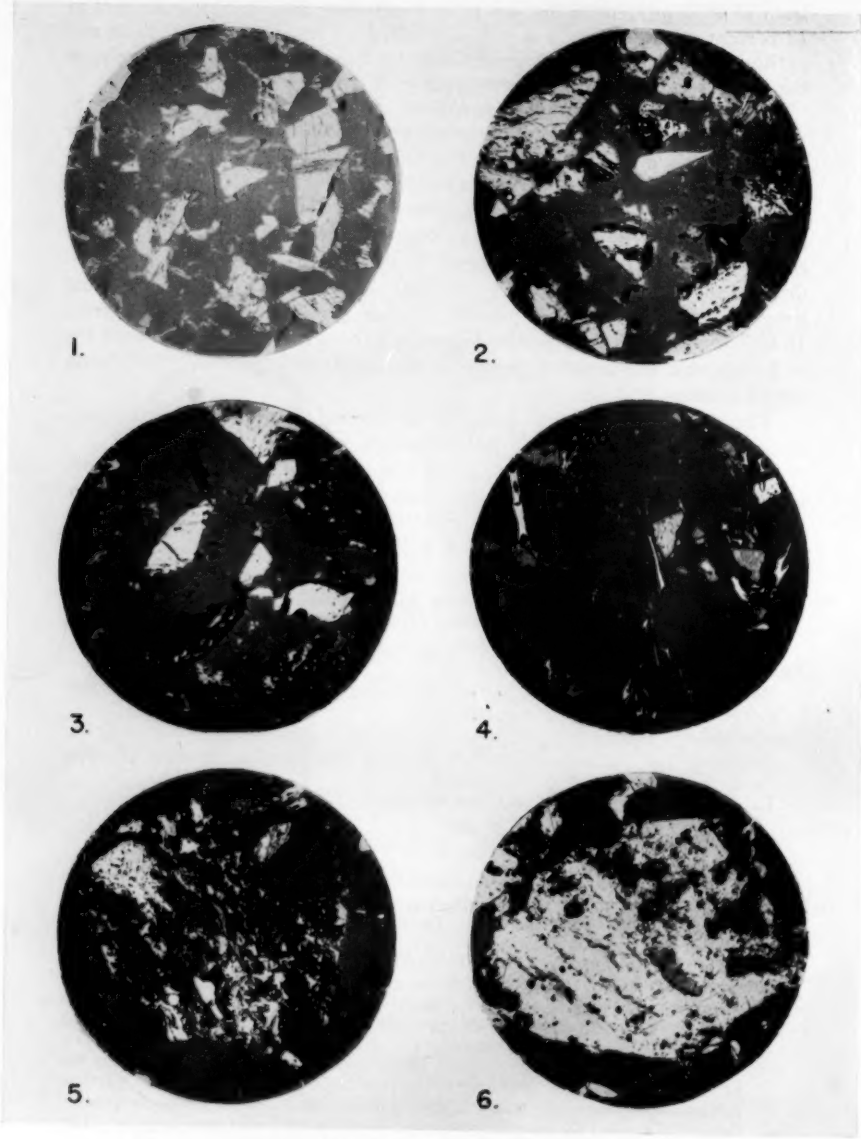

FIG. 11. Emery coal.

− 4 to + 1 inch and from 14 to 23 percent in the − 4 to + ¼ inch size. Dull coal, composed of dull clarain, durain, fusain and semifusain, was concentrated, in the same sizes, from 36 to 51 percent, and from 34 to 47 percent, in respectively 20 and 28 percent of the original run of mine sample.

Although the discrepancies between the concentrations of dull coal and opaque matter are rather striking at first sight they can be readily explained by calculation.

When using the maceral composition of the banded ingredients, as shown in Figure 7, one can compute the total amount of opaque matter that is contributed by bright and dull clarain, by durain, and by fusain and semifusain (for the last two mentioned 100% is used). By doing so the pounded coal of − 4 to + 1 inch size that has 51 percent dull coal should have 25 percent opaque matter, against 21 percent before it was pounded. These figures compare with 21 and 18 percent that were obtained by the maceral analyses. That the latter are from 3 to 4 percent lower than the former may be explained by the fact that it is rather difficult to arrive at a perfectly reliable average for the maceral composition of the banded ingredients.

From the above it may be concluded that a banded ingredient analysis alone is insufficient. It should be accompanied by a maceral determination, if not on the whole sample, then at least on the different banded ingredients, which may have largely varying maceral compositions.

Although a sizable concentration of dull coal was obtained, this was not accompanied by a substantial increase in the amount of opaque matter. Therefore the question remains: has a different coal been prepared? The proximate analyses showed that, at least chemically, this was not the case. However, it remains to be seen what effect, if any, the distribution of opaque matter within the coal will have on its coking properties. One could almost make any combination of banded ingredients with varying amounts of macerals, to obtain a coal that has 21 percent opaque matter. The banded ingredients occur in finely crushed coal as separate units, whereas the macerals do not. These units, or coal fragments, probably will react separately on carbonization, and as a result may behave differently according to their individual composition. This thought is substantiated by microscopic analyses on coke prepared by blending coals of different rank. In an article by Jenkner (7), illustrations of polished sections of coke show that particles of higher rank material react separately and differently from those of lower rank origin.

Coking tests were not carried out on the different samples prepared of the St. Rose No. 5 seam, because their high ash and sulphur content did not warrant this. However, it is hoped that these investigations may be continued, and that in the future the possible relationships as discussed here may be further examined.

1, clean coal at 1.30 sp. gr., very high in vitrinite (× 33); 2, fairly dirty coal at 1.50 sp. gr., black is shale (× 33); 3, dirty coal at 1.70 sp. gr., very high in shale (× 33); 4, concentration of fusain, mostly as splinters, in screensize − ¼ to + ⅛ inch at 1.60 sp. gr. (× 110); 5, opaque matter in carbonaceous shale (× 110); 6, finely divided pyrite in clean bright coal (× 70).

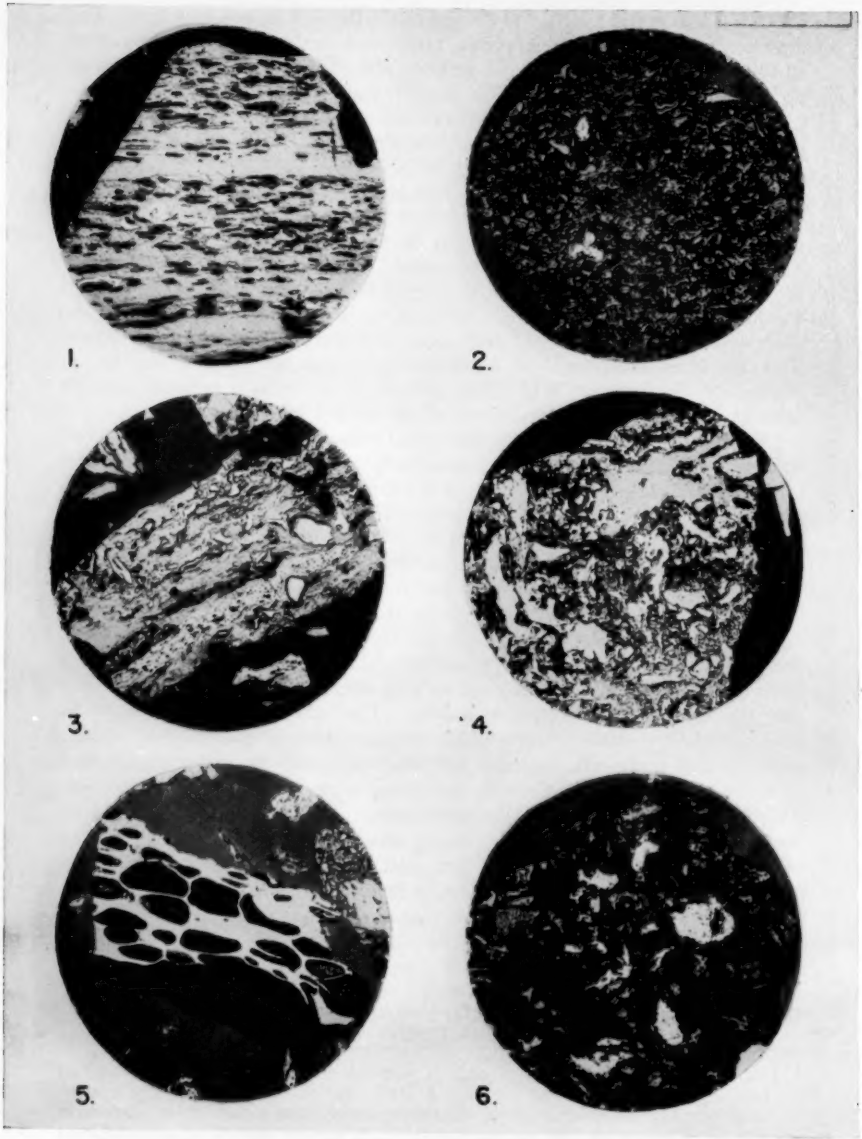

FIG. 12. Harbour coal.

CONCLUSIONS

Gravity separation of different screensizes materially affects the petrographic composition. Vitrinite and exinite are concentrated in the lighter fractions, opaque matter together with shale and pyrite in the heavier ones. The best separation results are obtained with the finest screensizes. Commercial washing probably has an adverse effect on the strength of coke, because the inert components (opaque matter) are reduced and the swelling components (vitrinite) are increased.

Dull coal components, high in exinite and/or opaque matter, can be concentrated by screening, but even more so by crushing of the larger screen sizes by means of elastic pounding and subsequent fine screening. However, the success that may be obtained is related to the distribution of the dull coal components through the section of the seam. Only when these components are separated by bright coal, high in vitrinite, can sizable concentrations be expected.

Banded ingredient analyses alone are insufficient. They should be accompanied by maceral determinations, if not on the whole sample, then at least on the different banded ingredients, which may have largely varying maceral compositions. The opposite is equally true, particularly in relation to studies of coking coals, since a coal containing, e.g., 20 percent opaque matter may be composed of greatly varying amounts of banded ingredients.

ACKNOWLEDGMENTS

The authors are much indebted to Messrs. J. R. Donaldson, M. S. Barss, and T. F. Birmingham of the staff of the Coal Research Division of the Geological Survey of Canada, for their valuable assistance with the microscopic and sampling work. Grateful acknowledgment is also given to Mr. M. Bates, the chemical engineer of the Dominion Coal Co. Ltd., who prepared most of the proximate analyses that were used in this report.

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1, spores (exinite) in groundmass of vitrinite (× 110); 2, dense spores, typical for so-called bony bands in Harbour seam. Cut in bedding plane (× 110); 3, micrinite composed of small particles, well distributed (× 110); 4, massive micrinite surrounded by spores (× 110); 5, particle of fusain with empty, or gas filled cell cavities, except at extreme right, where they are filled with pyrite (× 110); 6, massive micrinite in carbonceous shale (× 110).

REFERENCES

1. Atlas für angewandte Steinkohlenpetrographie, 1951, compiled by Abramski, C., Mackowsky, M. Th., Mantel, W., and Stach, E., Verlag Glückauf G. M. B. H., Essen, p. 329.
2. Elliot, C. D., 1944, Ironmaking at the Appleby-Frodingham works of the United Steel Companies, Ltd.: Iron and Steel Inst., Special Rpt. no. 30.
3. Hacquebard, P. A., 1950, The nomenclature and classification of coal petrography: N. S. Dept. Mines and N. S. Research Foundation, Conference on the Origin and Constitution of Coal, Crystal Cliffs, Nova Scotia, June 21–23, p. 8–38.
4. ——, 1951, The correlation, by petrographic analyses, of No. 5 seam in the St. Rose and Chimney Corner coalfields, Nova Scotia: Geol. Survey Canada, Bull. 19, 33 p.
5. ——, 1952: Opaque matter in coal: Econ. Geol., vol. 47, no. 5, p. 494–516.
6. Hoffmann, H., and Kühlwein, F. L., 1935, Rohstoffliche und verkokungstechnische Untersuchungen an Saarkohlen: Glückauf nr. 27, p. 625–639; and nr. 28, p. 657–665.
7. Jenkner, A., 1952, Neue Gesichtspunkte zur Frage des Einflusses der Mahl-und Mischanlage für Kokskohle auf die Kokseigenschaften: Glückauf Heft 15/16, p. 363–367.
8. Kühlwein, F. L., 1935, Ergebnisse von Schwelversuchen mit schwelwurdigen Mischungen und Aufbereitungserzeugnissen von Steinkohlen: Glückauf nr. 45, p. 1078–1089.
9. ——, 1937, Bedeutung der angewandten Kohlenpetrographie für Kohlengewinnung., Kohlenaufbereitung und Kohlenveredelung: Congrès Stratigr. Carb. Heerlen, 1935, Tome II, p. 538–601.
10. ——, and Abramski, C., 1939, Praktische Ergebnisse bei Kohlenauswahl, Kohlenmischung und Koksverbesserung für die Hochtemperaturverkokung: Glückauf nr. 44, p. 865–874; and nr. 45, p. 881–890.
11. ——, 1947, Ways to the best possible utilization of coal: Special Edition Bergbau-Archiv, vol. 5/6, 21 p.

A SUGGESTED SOURCE OF THE THIOPHILE ELEMENTS OF THE TERTIARY ORE DEPOSITS OF THE SOUTHWEST

J. R. HILLEBRAND

ABSTRACT

Modern theories of petrogenesis coupled with the available data on the metal content of rocks suggest ore solutions are not derived either from metamorphism of crustal material or through the crystallization of magmas resulting from palingenesis of crustal material. Either of these processes present problems of concentration and in explaining some field relations. A review of the complex thermal histories of several mining districts indicates an equally complex source for the various magmas and ore solutions. The source is believed to be a zone of magmation at the base of the crust involving both crustal and sub-crustal material. The ore metals are believed to have been originally dispersed as segregations in the sub-crust. The theory offers a new explanation for metallogenic provinces, the relation between structural provinces and ore deposits, and the association of ore deposits with intrusives.

INTRODUCTION

THIS paper presents some conclusions regarding the source of the metals of the Tertiary ore deposits of the southwestern United States and northern Mexico. What is presented concerning the source of the metals for these deposits the writer does not attempt to apply universally to deposits of other areas or other ages. I am aware this discussion is inferred from data subject to varied interpretation. It is presented to stimulate further discussion.

The discussion may conveniently be divided into three sections: 1) thiophile (sulphur-loving) elements in the crust and their concentration; 2) a theory of source; 3) some consequences of the theory.

The writer wishes to express his appreciation to Harrison Schmitt of Silver City, New Mexico; T. S. Lovering of the United States Geological Survey, Denver; and B. S. Butler, E. B. Mayo, and R. L. DuBois of the University of Arizona, Tucson, for critically reading the manuscript and offering suggestions for its improvement.

THIOPHILE ELEMENTS IN THE CRUST AND THEIR CONCENTRATION

Metal Content of Rocks

Data on the metal content of all rocks are far from complete. First, the number of analyses are few. Second, the analyses are commonly given as average values rather than maximum, mean, and minimum values. Third, an area is seldom thoroughly sampled so that for what mass a given analysis is representative remains unknown. The analyses quoted in Table 1 were

assembled by Rankama and Sahama (16)[1] from various sources. All are average values.

TABLE 1

METAL CONTENT OF ROCKS (RANKAMA AND SAHAMA, 1950)

Copper	%	*Lead*	%
mafic igneous rocks	0.0149	mafic igneous rocks	0.0009
inter. igneous rocks	0.0038	felsic igneous rocks	0.0019–0.003
felsic igneous rocks	0.0016	sandstones, shales	0.002
Mississippi silt	0.0034	limestones, dolomites	0.0005–0.003
Ital. argill. sed.	0.0192		
limestones	0.0020		
dolomites	0.0013		

Gold	%	*Silver*	%
mafic igneous rocks	0.00002	mafic igneous rocks	0.0007
felsic igneous rocks	0.0001	felsic igneous rocks	0.00009–0.0008
sandstone	0.000003	terrug. sed., Africa	0.00007
limestone	0.0000009	sandstone	0.00004
		limestone	0.00002

Zinc	%
mafic igneous rocks	0.009
inter. igneous rocks	0.01–0.02
felsic igneous rocks	0.003–0.015
shale	0.02–0.1
sandstone	0.002
limestone	0.005

Concentration of the Metal Content of Rocks

Since the primary content in rocks of the thiophile metals is so small, consideration must be given to whether it can be concentrated into ore deposits. For example, Mason (10, p. 43) has calculated that ore bodies of copper of 1 percent grade, of zinc of 4 percent grade, and of lead of 4 percent grade represent concentrations 140, 300, and 2,500 percent greater than the estimated amounts of copper, zinc, and lead respectively in the crust.

Concentration may be achieved either through metamorphism or palingenesis (magmatism). As used in this discussion, the latter process includes concentrations resulting from the crystallization of a liquid silicate melt, while the former process includes concentrations resulting from changes throughout which the system remains largely in the crystalline state.

Concentration by Palingenesis of Crustal Material

Available evidence suggests magmas are palingenetic in origin; that is, they result from the fusion of crustal and sub-crustal material. Seismic data indicate the sialic crust is crystalline. That no permanent magma zone exists in the simatic sub-crust is suggested: 1) because pressure alone apparently cannot impart to vitreous basalt the rigidity and viscosity required by seismic

[1] Numbers in parentheses refer to References at end of paper.

observations as indicated by Birch and Bancroft (1), it is not likely that at any depth below the crust the temperature permanently exceeds the melting range of basalt at that depth (19, p. 358).

Consider a magma undergoing crystallization. Goranson's (6) experiments indicate a granitic magma may contain in solution, depending on P-T relations, a maximum of about 10 percent water. Any amount above this presumably separates as an immiscible phase. Thus in the middle stages of magmatic crystallization the system consists of: 1) a liquid silicate phase, composed predominantly of silica and alumina, with soda, potash, magnesia, calcium oxide, the iron oxides, water, and "mineralizers"; 2) a crystalline phase, composed chiefly of silicate minerals; 3) a water phase, composed predominantly of water and "mineralizers." The latter phase may exert considerable vapor pressure, will readily move to areas of reduced pressure, and thereby separate from the area of the solid and liquid phases. In the final stages of crystallization the liquid silicate phase may be quantitatively small and soluble in the more abundant water phase. This can be referred to as the "fluid end phase." The present question—in which phase do the metals concentrate?

Analyses quoted by Rankama and Sahama (16) show zinc may be present in the mafic silicate minerals and lead in apatite and potash feldspar, but the quantities are negligible. In both cases the metals are concentrated in the later fractions of the non-solid phases (16, p. 710, 733). Their presence in the silicates may represent post-crystallization introduction into the silicate lattice.

Gold, silver, and particularly copper are concentrated in the sulphides of igneous rocks. Recent work by Moorehouse (11) has shown that sulphides are of late crystallization and thus the product of the final fractions of the fluid phases. At the time of the sulphide precipitation, the existing fluid phase may be the "fluid end phase," or a phase approaching it. For the present it will be considered to be the phase in which the thiophile elements are concentrated before deposition.

The "fluid end phase" is presumably distributed throughout the interstices of the precipitated crystals. All or part will remain in the interstices while none or part may migrate to some other area. That which remains in the interstices will either precipitate minerals in the interstices, or react with the existing minerals forming new minerals or performing minor lattice substitutions without the formation of new minerals. Many deuteric reactions fall within the latter two categories.

Two questions now arise: first, what is the nature of the "plumbing system" and the character of the "fluid end phase" which permits its migration from the innumerable interstitial areas into the relatively few feeder channels of an ore district; second, what volume of rock would be required to supply the metal of some of the great southwestern mining districts?

Concerning the first question, the "plumbing system" must obviously be inter-connected and, as shall presently be shown, must be inter-connected through a large volume of rock. The driving force of the solution must be provided by the solution itself, for its viscosity is such that any external pressure would disperse it into the interstitial areas as readily as it would drive it

along the larger channelways (which external rock pressure would tend to close).

Copper is one of the more abundant base metals in rocks. Felsic to intermediate granitic rocks, schists, and gneisses (the common basement rocks and those subject to palingenesis or metamorphism in the southwest), average 50 parts per million copper. If the copper of some of the large districts of the southwest—Bingham, Miami, Morenci, or San Manuel—were to be derived from the hydrothermal solutions resulting from the crystallization of a palingenetic magma, it would require the fusion of ten to twenty cubic miles of the sial crust. Since the total metal content of the rock very likely is not removed by the fugitive portion of the "fluid end phase," a greater volume of rock is actually required. The large volumes of palingenetic magma required suggest to the writer that such magmas are not the source of ore solutions.

Finally, as Ramberg (15, p. 186) states: ". . . it is to be expected that the same elements which are "fugitive" and mobile in the late magmatic stage will also be relatively easily mobilized during progressive metamorphism." If ore solutions were a differentiation product of palingenetic magmas it might be expected that they would become activated during the formation of the magma, and precede the intrusion of the magma(s) into the upper crust. This would be contrary to the known relations, and suggests ore solutions are not derived through palingenesis of crustal material.

Concentration by Metamorphism of Crustal Material

Few data are available on the mobility of the thiophile elements under various metamorphic conditions, Ramberg (15, p. 265) believes metamorphic mobilization and concentration were responsible for many of the sulphide lenses of metamorphic terrains. However, the Tertiary ore bodies of the southwest are in many, if not most cases, in rocks that lack metamorphism (other than hydrothermal alteration) related in time to the mineralization. That metamorphism of the basement rocks at depth moved the metals into the non-metamorphosed zones where they were precipitated is doubtful, in that like palingenesis it requires the removal of metals from huge volumes of rock.

Recent work bearing on this question has been done by Shaw (17), who studied the trace element distribution of a metamorphic terrain in New Hampshire. He finds that the concentration of most elements remains constant during regional metamorphism. Nickel and copper show a slight decrease, while lithium and lead show a well-defined increase, of the order of 100 percent.

Considerations from Actual Occurrences

While theoretical considerations do not give conclusive answers to whether or not the thiophile metals of the southwestern Tertiary ore deposits could be concentrated by metamorphism or palingenesis of crustal material, several areas pose interesting problems to this supposition.

Colorado Front Range.—The geology and ore deposits of the Front Range mineral belt of Colorado were recently described by Lovering and Goddard

(9). The Front Range consists of a core of Precambrian granites, gneisses, and schists flanked by Paleozoic and Mesozoic sediments. Two ages of ore deposits are present: Precambrian and Tertiary. Concerning the Precambrian ores Lovering (8, p. 273) states: "In contrast to the Tertiary ores of Colorado, The Precambrian ores are chiefly valuable for their copper content." The Tertiary ores are valuable for their gold, silver, lead, and zinc; copper is minor or absent.

If the metals for the deposits of both periods were concentrated from the rocks of the Precambrian complex, why is the metal content of the two mineralization periods so different?

Old Hat, Arizona.—Consider a second case on a local scale, that of the Old Hat district, Pinal County, Arizona. Two deposits are present; the disseminated copper deposit at San Manuel, and the gold-silver-lead-zinc veins at Tiger, 2,500 feet to the north. The San Manuel deposit occurs in Precambrian quartz monzonite and intrusive monzonite of Laramide (?) age. It is cut by post-mineral rhyolite dikes that are pre-mineral at Tiger. Production from Tiger through 1951 is: gold, 405,000 ounces; silver, 1,450,000 ounces; lead, 111,000,000 pounds; zinc, 62,000,000 pounds; copper, 6,000,000 pounds. The San Manuel deposit contains over eight billion pounds of copper, with small amounts of gold, silver, and molybdenum.

If the ore solutions for these deposits resulted from two periods of metamorphism or palingenesis in the same Precambrian basement, why were the solutions of the first period so enriched in copper and lacking in other metals, while those of the second period were relatively lacking in copper but containing abundant lead and zinc?

A THEORY OF SOURCE

Assuming sampling is representative of the major fraction of the mass of the crust, the preceding discussion suggests the metals of the Tertiary ore deposits of the southwest could not be concentrated from continental crustal material. This leads to a consideration of a sub-crustal source for these metals.

The density stratification present within the earth today, coupled with the apparent uniformity of rate of geologic activity from at least the late Precambrian to the present, suggests that at some time within the history of the earth it was capable of rapid and rather complete density separation. This process may be, and probably is, continuing at present, but presumably at a much reduced rate. The thickened sial of the crust that results in mountain elevations [2] is believed, in part, to represent sialic material originally present as

[2] Geodetic work indicates isostatic compensation is of a modified "root" type, and further, that existing mountain ranges, continental basins, and plateaus are in good isostatic balance (3). Since throughout the southwest there are areas that were stable for geologic period(s) below sea level and which are now stable as mountain elevations, a thickening of the sial crust must have occurred in these areas. This thickening may have occurred through structural or igneous-metamorphic processes. In geosynclinal belts the thickening may result from the folding, overthrusting, and metamorphism attendant upon the change of the geosyncline from a stable negative to an unstable positive structural element. Overthrusting may also account for the thickening in some Cordilleran ranges. But there are other areas, like the Colorado

segregations within the sub-crust (the zone within the earth between approximately 40 and 400 kilometers) which have migrated, for causes unknown, to areas at the base of the sialic crust and there became incorporated into the sialic portion. Associated with, and accompanying the sial segregations are metalliferous segregations that are the source of the metals of ore deposits. These segregations could occur separately in the sub-stratum or within the sial segregations.

That such segregations exist is suggested by the fact that physical separations are never perfect; some small fraction of the "foreign" material always remains. This fraction admittedly is very small, but considering the mass of material involved the amount may be quite large. For example, a continental crust, 40 kilometers thick, is only one-twentieth of the mass of the zone extending from 40 to 400 kilometers within the earth. Since most of the crust has existed since Precambrian time, the amount of sial that must be added to account for the mountain systems originating in this manner since that time is quite small, probably a fraction of a percent of the total mass of the sub-crustal zone.

At this point a review of the Mesozoic and Tertiary thermal histories of some southwestern mining districts is of interest. With the exception of the Old Hat district, the sequences are largely assembled from published reports.

Old Hat District, Arizona

1) intrusion of quartz monzonite porphyry plugs and dikes
2) intrusion of diabase
3) hydrothermal alteration at San Manuel
4) copper mineralization at San Manuel
5) erosion
6) intrusion of andesite porphyry dikes associated with andesite and basalt flows
7) intrusion of rhyolite and rhyolite breccia plugs and dikes
8) gold-silver-lead-zinc mineralization at Tiger

West Mountain District, Utah (Stringham, 1953)

1) granitization of quartzite forming orthoclase granite, granite, orthoclase syenite, quartz monzonite, syenodiorite, quartz diorite, granodiorite, diorite, and actinolite syenite
2) intrusion of granite porphyry and quartz latite porphyry
3) alteration of the following types in the following sequence:
   a) illite-kaolinite (localized)
   b) biotite-sericite (widespread)
   c) chlorite-biotite (localized)
   d) quartz-sericite (localized)
   e) quartz veinlet filling
4) copper mineralization
5) sericite-allophane alteration (widespread)
6) lead-zinc mineralization

Plateau and many of the Cordilleran ranges, where structural thickening does not appear to have occurred, yet the areas are strong positive elements. For these cases it is concluded crustal thickening resulted from the addition of sial to the base of the crust. This may be achieved either by lateral migration of sial at the base of the crust or, to a lesser extent, by the addition to the crust of sial segregations from within the sub-stratum.

Central District, New Mexico (Lasky, 1936; Schmitt, 1954; Spencer and Paige, 1935)

1) injection of two periods of quartz diorite sills
2) weak quartz-pyrite mineralization
3) injection of granodiorite "stocks"
4) injection of granodiorite dikes
5) development of skarn zone, magnetite mineralization
6) zinc mineralization at Hanover
7) injection of quartz monzonite facies of the "stocks" and the quartz monzonite dikes
8) zinc mineralization in the Bayard area; alteration of the Santa Rita stock
9) copper mineralization at Santa Rita
10) erosion
11) deposition of a thick series of lithic and crystal tuffs
12) injection of quartz latite plugs and dikes
13) weak pyrite, quartz-pyrite, and quartz-calcite mineralization
14) extrusion of basalt and andesite flows

Ajo District, Arizona (Gilluly, 1946)

1) intrusion of Chico Shunie complex (quartz monzonites, some potash granite, albite granite, quartz diorite, and trondjemite, which may be of several ages). A complex of rheomorphic origin?
2) development of cataclastic and brecciated texture in the Chico Shunie complex
3) erosion
4) extrusion of andesites, andesitic tuffs and breccias; albitization and introduction of quartz yielding keratophyres and quartz keratophyres flows, breccias, and tuffs
5) intrusion of Cornelia stock
   a) development of dioritic border facies; formation of narrow (few feet wide) hornfels zone in country rock
   b) development of equigranular and porphyritic quartz monzonite facies
6) formation of replacement pegmatites; local orthoclasation
7) formation of magnetite in Cornelia stock
8) albitization and sericitization of Cornelia stock and adjacent rock
9) copper mineralization
10) erosion
11) extrusion of andesites, latites, and basalts.

Central City Area, Colorado (Lovering and Goddard, 1950)

1) intrusion of dikes and stocks of sodic monzonite and quartz monzonite porphyry
2) intrusion of dikes of alaskite porphyry
3) intrusion of dikes of alaskite syenite
4) intrusion of dikes of bostonite and bostonite porphyry
5) pyritic gold mineralization (the predominant mineralization)
6) galena-sphalerite with gold, silver, mineralization
7) intrusion of dikes of biotite latite
8) telluric gold, silver, mineralization

These examples illustrate the complexity occurring in mining districts that record magmas, alteration solutions, and ore solutions of varying types having been withdrawn in various sequences. This suggests an equally complex source, for the source conditions must be as complex as their products.

The accompanying diagrams illustrate the sequence of events visualized by the writer.

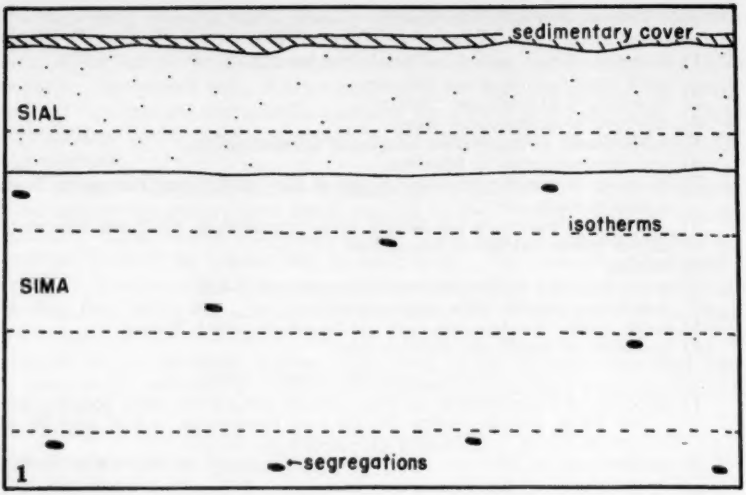

FIG. 1. Isotherms shown as dashed lines, segregations in black. Sedimentary cover is cross-hatched; sial, stippled; sima, white.

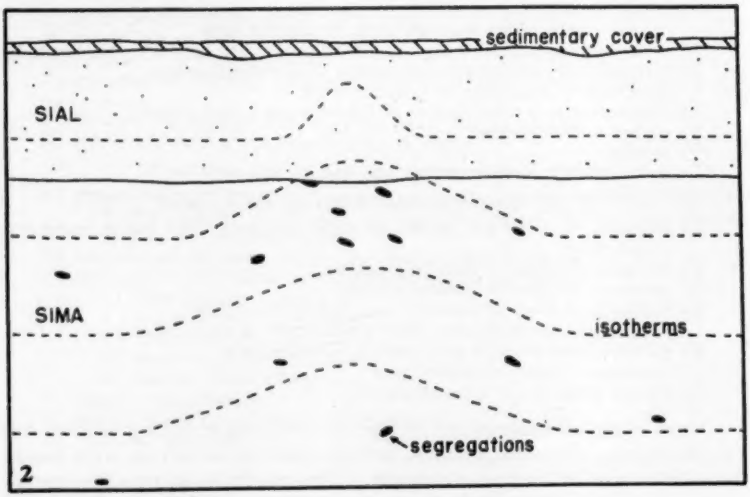

FIG. 2.

Initially a portion of the base of the crust is subjected to high thermal energy [3] coupled by the migration of sial and metalliferous segregations from within the sub-crustal zone to this area (Figs. 1, 2). The segregations may be in a non-crystalline state. This results in a zone of magmation near the base of the crust (Fig. 3), which is a complex consisting of silicate melts, fluids concentrated in the elements of ore deposits, and rocks undergoing various types of metamorphism. It is the movement of material from this zone into the upper portions of the crust that results in the history of thermal activity observable in the rocks today.

The thermal effects in the upper crust may be of two extreme types: the one is characterized by abundant volcanism and small shallow intrusions as stocks, sills, and dikes of undoubted magmatic origin; the other is characterized by intensive regional metamorphism and rheomorphism. All gradations between the two types exist. The ore deposits of the southwest are associated, however, with regions where volcanism and intrusions of the shallow sub-volcanic association are prevalent. Erosion has not been deep enough to expose widely the zone of regional metamorphism connected with the Tertiary thermal cycle.

Magmas may be generated in two areas: 1) in the zone of regional metamorphism, and 2) in the zone of magmation (Fig. 3). Those from the zone of regional metamorphism may be largely crystalline and move essentially as solid aggregates, in which case they are technically not magmas (silicate melts). This movement has been discussed by Ramberg (15, p. 259). The magmas from the zone of regional metamorphism may not be connected by channels with the zone of magmation. Unless they are, there can be no ore deposits associated with them, for they will remain separated from the metallic concentrations in the zone of magmation.

Magmas from the zone of magmation may be due to: 1) palingenesis of the lower portions of the crust and sub-crust; 2) sial segregations from the sub-crust accumulated in the zone of magmation. Magmas from this zone will be largely liquid. They are the source for the volcanism and shallow sub-volcanic intrusions of the upper crust. These magmas may form differentiation chambers in the upper portions of the crust, which will ultimately crystallize to stocks of complex composition. Needless to say, this is not the only way in which complex intrusives of the sub-volcanic association may originate.

Magmas, alteration solutions, and ore solutions are regarded as separate products of the zone of magmation. In some cases, however, the host rock alteration was accomplished by the ore solution, and a separate alteration solution was not active. Metallic mineralization occurs when metalliferous solutions of the magmation zone, derived from the metalliferous segregations of the sub-crust, ascend to the uppermost parts of the crust along the channels

[3] That orogeny, metamorphism, and magmatism are all closely related is apparent. That they are also highly varied is evident when they are compared in, for example, the geosynclinal, volcanic plateau, and Cordilleran basin-and-range settings. The writer leans toward the view that neither orogeny, metamorphism, nor magmatism is the cause (except locally) of the other, but all owe their origin to re-adjustments of matter and re-distribution of energy in the sub-crust. The driving force is generally considered to be an increase in thermal energy, whose source and method of concentration is one of the outstanding problems of modern petrogenesis.

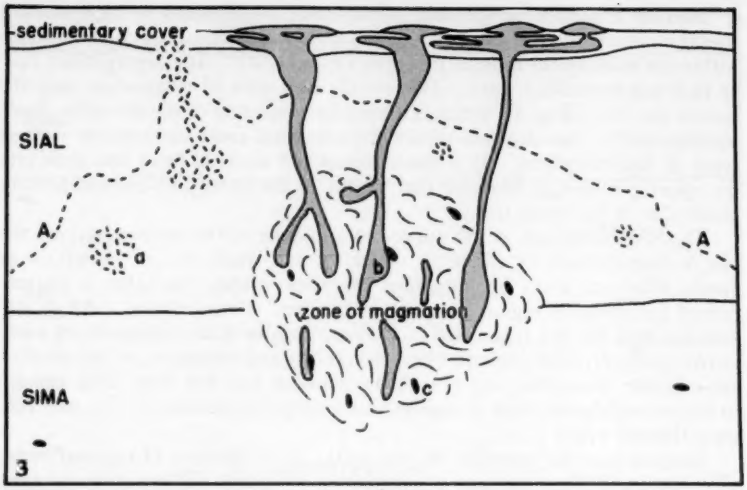

FIG. 3. Line A-A marks the limit of regional metamorphism. (a), "magma" generated in zone of regional metamorphism. (b), magma and intrusions from zone of magmation. (c), metalliferous concentrations in zone of magmation.

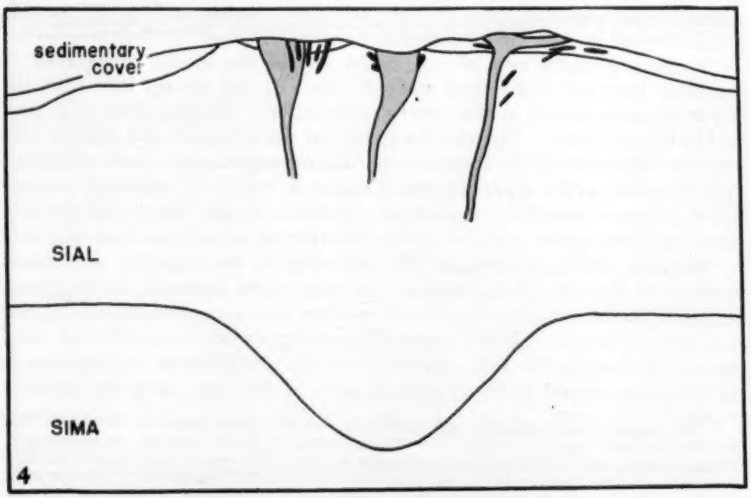

FIG. 4. Ore bodies are shown in black, intrusives in gray.

utilized and created by the pre-ore volcanic magmas. As Schmitt (12, p. 58) states: "It seems likely that the primary factor in the localization and association of 'stocks,' contact pyrometasomatism and ores, is a deep-cutting break of one sort or another in the earth's crust, that the pyrometasomatic deposits are not derived from the 'stocks' but that their association is the result of localization along mutual outlets to the earth's surface." The metallogenic paragenesis will depend on: 1) the number and composition of the source concentrations contributing metals; 2) the order in which the concentrations ascend to the ore traps.

It is possible that the metalliferous concentrations may become incorporated in the rising magmas and reach one of the differentiation chambers in the upper portion of the crust. If ore deposits are to result, it is believed necessary that the metals remain in a concentrated phase and not disperse in the magma. Should they disperse, the problem is faced of re-concentrating them in sufficient volume and concentration. It also follows that the metals must remain, at least in part, separate and concentrated in the zone of magmation.

Topographic elevation will result from the crustal thickening due to structural repetition and/or the addition of sial to the base of the crust. This further results in erosion removing much of the overlying rock (particularly the effusives of the igneous stage) and exposes the shallow intrusives and the specially associated ore deposits (Fig. 4).

The ore solutions are not visualized as an end product of magmatic differentiation in the simplified sense of the residua of an originally homogeneous silicate melt. Ore deposits are always younger than the associated intrusives; the only association which can be demonstrated is spatial and not genetic. The latter is inferred. The writer believes the relation between the igneous rocks of a mining district and the ore solutions is fraternal and not paternal; they both have their origin in the zone of magmation at greath depth. The reader may consider this zone to be the deep-seated batholith of which the exposed stocks are the upward projections and the ore solutions the late differentiate. However, the complex character of the zone of magmation and the complex series of its differentiates does not fit the batholith parent to ore solutions described in the literature (see, for example, Emmons, 4). Further, this batholith may be exposed by erosion (4), while it is doubtful that erosion ever proceeds deep enough to expose the zone of magmation.

SOME CONSEQUENCES OF THE THEORY

The size, number, and composition of the ore deposits in an area will depend in part on the size, number, and composition of the metallic or sial-metallic segregations tapped during the magmation cycle. The latter depends on the conditions in the earth during the differentiation into the zonal layers. That similar conditions probably existed over large areas may explain the existence of metallogenic provinces. If conditions favored segregation of a particular metal (with respect to other metals) at some locality in an otherwise uniform physico-chemical zone, it probably favored it elsewhere in the zone. Presumably this favoritism would be reflected in ore deposits derived

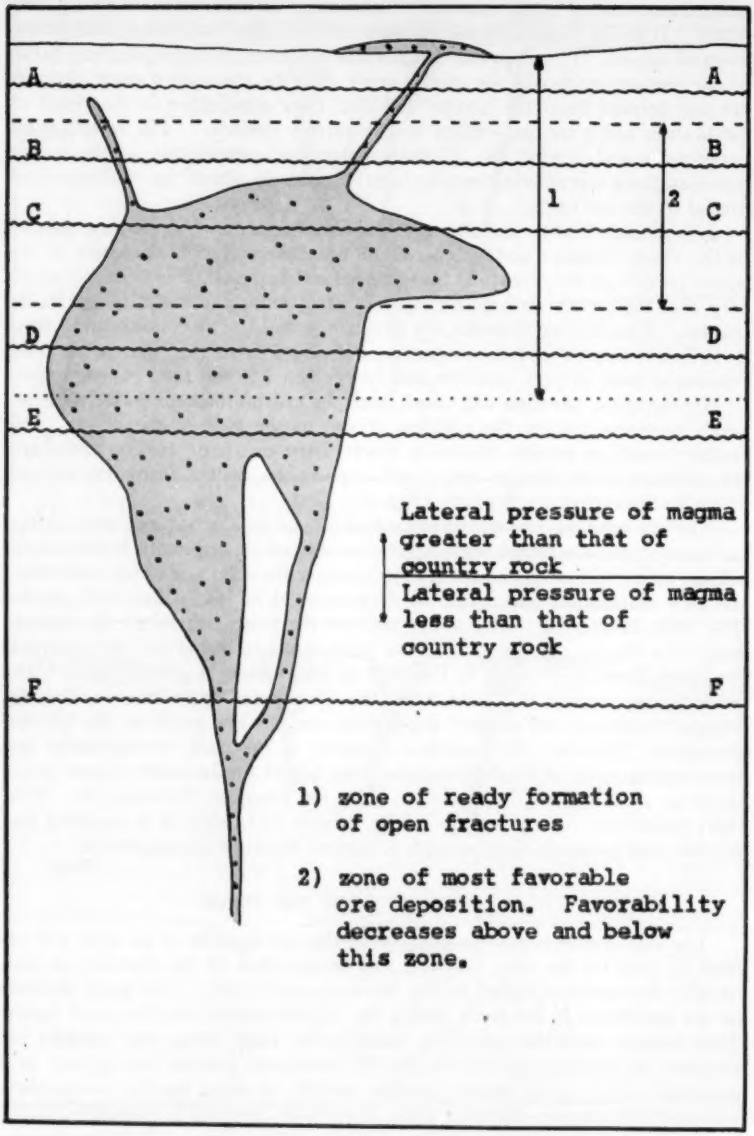
A
A
B
B
C
C
D
D
E
E
F
F
1
2
Lateral pressure of magma greater than that of country rock
Lateral pressure of magma less than that of country rock
1) zone of ready formation of open fractures
2) zone of most favorable ore deposition. Favorability decreases above and below this zone.

FIG. 5.

from these segregations, resulting in an area of ore deposits containing characteristic elements—a metallogenic province.

Furthermore, the structural-thermal history of the observable parts of the crust presumably reflects conditions in the sub-crust. If, then, the variations of the sial and metallic segregations in the sub-crust also reflect variable conditions in that zone, a close relationship may exist between the structural-thermal history of a region and the ore deposits that may be present in it. This may explain why copper deposits of the "porphyry" type appear to be confined (in North America) to the basin-and-range, whereas copper deposits of the Ducktown type appear to be confined to the folded geosynclinal belts.

The demonstration of a relation between depth of erosion of stocks and the number and size of associated ore deposits (2) must be considered in any theory of source. This fact is interpreted from the present theory as follows.

First, it must be noted that many of the largest "intrusives" owe their origin to granitization or rheomorphism in the zone of metamorphism. Some of the large batholiths of the Appalachian and Sierran geosynclines are examples. Batholiths here and elsewhere are generally unfavorable for ore deposits. Previously this has been attributed to the depth of erosion—these bodies, as a consequence of their large areal exposure, were presumed eroded so deeply as to remove the associated ore deposits. In the present theory the unfavorability is related to origin—the larger "intrusives" usually are not derived from, and may not be connected to, the zone of magmation and are, therefore, less favorable.

Ore deposits spatially associated with an intrusion are generally found near the margins rather than within the intrusive. In some instances, areas of carbonate rock for example, the country rock may be chemically more favorable. In other instances, the country rock has undergone more deformation and will possess better ore solution channelways and ore traps. Ore solutions following the channelway of the intrusion will, on nearing the surface, spread out into the channelways created by the deformation related to (but not necessarily caused by) the magma emplacement. They will move along these channelways and at favorable locations (ore traps) the metallic content of the solutions is deposited.

Magmas arise from the zone of magmation along relatively confined channelways. At some point near the surface, the lateral pressure exerted by the magma may exceed that exerted by the wall rock and the magma spreads out along available channelways or creates new ones, forming a mushroom-shaped body which may be laccolithic, stock-like, or chonolithic depending on its contact relations.

The tertiary ore deposits of the southwest appear almost universally to have been deposited within two to three miles of the surface, and commonly within ½ to 1½ miles of the surface. Reasons for precipitation within this zone are numerous, and a complete discussion is beyond the scope of this paper, if not beyond present knowledge. It does appear, however, that the bottom of the zone of ore precipitation may roughly coincide with that of the zone in which open spaces accompanying structural deformation are abundant. Presumably a magma may exert sufficient pressure that it may undergo lateral

expansion before the zone of ready formation of open fractures is reached. Its relation to the zone of ore precipitation is sketched in Figure 5.

Figure 5 also illustrates the relations between ore exposure of intrusion, and depth of erosion. At A–A, erosion has not penetrated into the zone of most favorable ore precipitation (ore zone). A few dikes may be present.

At B–B, the top of the ore zone is breached. The only igneous rocks exposed are in dikes.

At C–C, the center of the ore zone is exposed, while the igneous rocks present are dikes (some of which may be post-stock) and a stock.

At D–D, the base of the ore zone is reached, and the igneous relations are the same as in C–C.

At E–E, the ore zone has been removed, while the igneous rock relations are the same as in C–C.

At F–F, the igneous rocks exposed are the feeder dikes. The relations are the same as in stage A–A.

EDGEWATER, COLORADO,
May 20, 1954

REFERENCES

1. Birch, F., and Bancroft, D., 1942, The elasticity of glass at high temperature and the vitreous basaltic substratum: Amer. Jour. Sci., vol. 240, p. 457–490.
2. Butler, B. S., 1915, Relation of ore deposits to different types of intrusive bodies in Utah: ECON. GEOL., vol. 10, p. 101–121.
3. Daly, R. A., 1940, Strength and Structure of the Earth, Prentice-Hall, New York.
4. Emmons, W. H., 1933, On the mechanism of the deposition of certain metalliferous lode systems associated with granitic batholiths: Chapter VII, Ore Deposits of the Western States, Amer. Inst. Min. Met. Eng., New York.
5. Gilluly, J., 1946, The Ajo mining district, Arizona: U. S. Geol. Survey Prof. Paper 209.
6. Goranson, R. W., 1931, The solubility of water in granite magmas: Amer. Jour. Sci., 5th ser., vol. 22, p. 481–502.
7. Lasky, S. G., 1936, Geology and ore deposits of the Bayard Area, Central Mining District, New Mexico: U. S. Geol. Survey Bull. 870.
8. Lovering, T. S., 1933, Precambrian ore deposits of Colorado and southern Wyoming: Part V, Chapter VI, Ore Deposits of the Western States, Amer. Inst. Min. Met. Eng., New York.
9. Lovering, T. S., and Goddard, E. N., 1950, Geology and ore deposits of the Front Range, Colorado: U. S. Geol. Survey Prof. Paper 223.
10. Mason, B., 1952, Principles of Geochemistry, John Wiley and Sons, New York.
11. Moorehouse, W. W., 1953, Significance of accessory minerals in igneous rocks (abstract): Bull. Geol. Soc. Amer., vol. 64, p. 1455.
12. Schmitt, H., 1935, Structural associations of certain metalliferous deposits in southwestern United States and northern Mexico: Trans. Amer. Inst. Min. Met. Eng., vol. 115, p. 39–58.
13. Schmitt, H., 1954, personal communication.
14. Spencer, A. C., and Paige, S., 1935, Geology of the Santa Rita mining district, New Mexico: U. S. Geol. Survey Bull. 859.
15. Ramberg, H., 1952, The Origin of the Metamorphic and Metasomatic Rocks, Univ. of Chicago Press, Chicago, Ill.
16. Rankama, K., and Sahama, T. G., 1950, Geochemistry, Univ. of Chicago Press, Chicago, Ill.
17. Shaw, D. M., 1953, Trace element behavior in regional metamorphism (abstract): Bull. Geol. Soc. Amer., vol. 64, p. 1472.
18. Stringham, B., 1953, Granitization and hydrothermal alteration at Bingham, Utah: Bull. Geol. Soc. Amer., vol. 64, p. 945–991.
19. Turner, F., and Verhoogen, J., 1951, Igneous and Metamorphic Petrology, McGraw-Hill Book Company, New York.

THE ORIGIN OF THE SILICA OF THE BEDROCK HYPOGENE ORE DEPOSITS [1]

HARRISON SCHMITT

ABSTRACT

The known facts on the distribution of the silica in and associated with many ore deposits suggest that only a small proportion of this oxide is imported into the ore zone from distances measured in thousands of feet or more. Most of it appears to be derived from the desilication of alumino-silicate walls and transported for distances often measured in inches, and rarely more than hundreds of feet.

This belief suggests a unique approach to the theory of the character of the ore-forming fluids, and further, following Knopf, that the "magma" need not be called upon to supply much of the silica and perhaps none at all for many ore deposits.

Speculation on the nature of the ore-making fluids leads to the further suggestion that they are similar to volcanic emanations. The original environment of the ore body could be a mass of structurally open ground of one form or another that is the site of a pool or reservoir of condensate, connate, meteoric or sea water. This is activated by the "volcanic emanations." The alumino-silicate walls are attacked particularly by hot water and carbonic acid and the silicates broken down to form lower silica species and other minerals. The excess silica is moved to the more open ground. In the form of quartz, chalcedony, etc., it is progressively fractured and forms the channel and locus of deposition for most of the sulphides.

The most active agents and/or elements in the genesis of ore deposits are those among the most active and conspicuous in vulcanism and the solar system. Particularly these are H, O, C and S and Cl usually encountered as H_2O, CO_2, H_2S and simple chlorine compounds.

THE principal theme in chapter seven of W. I. B. Beveridge's recent book, "The Art of Scientific Investigation," is that sound new ideas do not necessarily spring from logic, which when used to arrive at a conclusion may be based on principles which are themselves suspect. Dogma feeds on dogma. He (3, p. 86) [2] quotes Theobold Smith as follows: "Research is fundamentally a state of mind involving continual reexamination of doctrines and axioms upon which current thought and action are based. It is, therefore, critical of existing practices."

Much of the theory of ore deposits is based on deductive reasoning from unproved principles, indeed, the inherent nature of the science leads to dogma and excessive respect for authority. S. James Shand in "Eruptive Rocks" (25, p. 191) when discussing authoritative comment on ore deposit theories says: "It is interesting to note the choice of verbs in these statements: it is *held*; it is *conceded*; would *agree*; universally *accepted*." Rightly

[1] Presented before the Society of Economic Geologists, Toronto, Ont. Nov. 9, 1953.
[2] Numbers in parentheses refer to References at end of paper.

or wrongly, one gets the impression that each of these writers was expressing the fashionable view rather than a deep personal conviction."

Therefore, should we not be more humble, and admit we do not know, even, perhaps, at the cost of starting anew? Incidentally, a disturbing recent trend, based on our unwarranted confidence, is the use of the commonly accepted framework of theory as a foundation for geophysical and geochemical deductions; these in a climate of largely laboratory experimentation and of little field observation.

The silica problem may almost be said to be the problem of ore deposits. For this reason, in so short a paper, it will be difficult to guard against violation of the rule of unity.

The term vein usually brings up an image of a quartz vein; the type that

TABLE I.

PAIRED ANALYSES.

Unaltered versus altered rocks of certain ore deposits.

	Ground Hog Mine, Vanadium, N. M.		Open Pit, Bingham, Utah		Castle Dome, Miami, Ariz.		Lavender Pit, Bisbee, Ariz.		Open Pit, Ajo, Ariz.	
	1	2	3	4	5	6	7	8	9	10
SiO_2	64.63	42.53	68.16	66.09	70.14	70.55	76.81	56.1–65.7	66.23	65.57
Al_2O_3	15.68	14.75	15.23	15.29	13.90	13.54	10.96		15.71	15.42
Fe_2O_3	2.75	7.98	1.29	3.30	1.92	.84	1.18		2.20	1.05
FeO	1.96	3.24			1.99	.99	.08		1.98	2.04
MgO	1.00	.09	2.30	4.15	.65	.58	.14		1.58	1.66
CaO	4.16	14.18	.62	.89	1.86	.27	.00		3.78	.39
Na_2O	2.10	1.18	1.24	1.99	2.65	.67	.26		3.89	3.33
K_2O	2.73	1.14	8.67	4.65	4.52	5.03	8.50		3.22	5.01
H_2O^-	.60	.40			.14	.95	.48		.03	.79
H_2O^+	1.51	3.67	1.78	2.30	1.13	2.13	1.17		.67	1.06
TiO_2	.31	.30	.66	.71	.58	.50	.13		.47	.36
P_2O_5	.20	.19			.21	.11	Tr		.24	.23
MnO	1.25	1.13			.12	.01			.08	.03
FeS_2		4.41			.03	3.56	.00			.20
ZrO_2	.00	.00								
BaO	.12	.07								.05
CO_2	.98	1.52					.00			.41
F										
Total	99.98	99.14	99.95	99.37	99.84	99.73	99.71		100.08	99.72

1. Granodiorite (birdseye) porphyry; analyses by Lawson Entwistle.
2. Granodiorite (birdseye) porphyry; strongly altered to epidote and pyrite; analyses by Lawson Entwistle; includes ZnS 1.76, PbS 0.17, $CuFeS_2$ 0.43. Bulk SG may have increased depending on porosity.
3. Most unaltered granite obtainable (29, p. 956, analysis 1). SG 2.61.
4. Average of 3 analyses of altered granite (29, p. 977, analyses 2, 3 and 5). SG ±2.65.
5. Average of 2 analyses of fresh quartz monzonite (14, p. 85, analyses 1 and 2). Bulk SG 2.65.
6. Average of 3 analyses of altered quartz monzonite (14, p. 85, analyses 3, 4 and 5). Bulk SG 2.45.
7. Granite porphyry (sill near Bisbee) (16, p. 77, analysis III). SG ±2.6?.
8. Silica content of ore in Lavender pit. 7 analyses, 13.9–20.2% sulphide, SG ±2.8?. These latter data were kindly provided by Phelps Dodge Corp.
9. Porphyritic hornblende quartz monzonite (8, p. 30, analysis 4). Bulk SG 2.65?.
10. Porphyritic quartz monzonite from center of pit (8, p. 30, analysis 7). Includes $CuFeS_2$ 1.00, $CuFeS_4$ 0.70, LiO .05. Bulk SG 2.65.

TABLE I.—*Continued.*

	Miami Dist., Miami, Ariz.		Ray Dist., Ray, Ariz.			Ely, Nevada		Tyrone, N. Mex.		
	11	12	13	14	15	16	17	18	19	20
SiO_2	66.84	65.31	65.58	72.87	72.79	59.46	64.73	70.18	66.64	68.11
Al_2O_3	17.46	19.38	16.47	12.89	13.83	17.52	14.41	14.47	15.57	16.84
Fe_2O_3	4.88	2.01	4.19	2.40	.89	3.46		1.54	1.91	.80
FeO	.74	1.13	2.25	1.76	1.30	2.68		1.78	1.94	3.53
MgO	1.14	1.28	1.29	.82	1.04	1.73	.76	.88	1.41	.50
CaO	.37	.34	1.29	1.90	.23	6.03	.44	1.99	3.50	.44
Na_2O	.53	.42	1.42	3.01	.40	3.05	.70	3.48	3.41	.44
K_2O	4.65	5.35	4.58	3.03	4.21	4.01	7.84	4.11	3.42	4.08
H_2O^-	.17	.22	.22	.26	.38	.53	.82	} .84	} 1.15	
H_2O^+	2.61	2.94	2.27	.24	2.07	.55	1.94			
TiO_2	.67	.61	.83	.66	.42	.71	.57	.39	.50	
P_2O_5	.03	.08	.06	.13	.11	.27	.10	.19	.19	
MnO	.02	.01	.06	.07	.02	.19		.12	.06	
FeS_2		.89			2.11	.13				
ZrO_2					.02					
BaO					.08		.04			
CO_2						.04				
F						.04			.09	
Total	100.11	100.44	100.51	100.44	100.31	100.40	100.25	99.97	97.98	94.74

11. Pinal schist (15, p. 159, analysis 2). No SG given.
12. Average of 2 analyses of protore (15, p. 159, analyses 8 and 9). No SG given. Includes Cu_2S 0.47.
13. Pinal schist (15, p. 159, analysis 1). No SG given.
14. Pinal schist, probably meta-rhyolite (15, p. 159, analysis 3). No SG given.
15. Average of 3 analyses of protore (15, p. 159, analyses 5, 6a and 7b). No SG given. Includes Cu_2S 0.61.
16. Weary flat monzonite (28, p. 39, analyses 1 and 2). SG 2.17 (bulk ?).
17. Sample of ore (28, p. 110, analysis 153). SG 2.52 (bulk ?). See ibid., p. 57 for comparison of gains and losses of four ores. Includes Fe 2.89, Cu 1.96, S 2.83, SO_3 0.22.
18. Daly's average granite (5, p. 9, analysis 4).
19. Daly's average quartz monzonite (5, p. 15, analysis 44).
20. Analysis of specimen from replacement vein. Computed: quartz 45.30, sericite 46.09, pyrite 6.68 (13, p. 27). Includes S 3.15.

most commonly carries ore minerals. In a general sense this implies a conduit filled with foreign matter that has come from a distant source, and that the fissure continues almost indefinitely downward. Indeed, these were the primitive conclusions. The idea has been accepted, albeit, not very critically, down to the present day. It appears to be one of those principles.

Adolph Knopf (9, p. 41–45) showed that the ankeritization of the walls of the veins of the Mother Lode in California resulted in a loss of silica far greater than needed for the gain of quartz in the adjacent veins. He concluded that the alteration supplied this quartz. These data have often been commented on, but the implications neglected.

That the silica closely associated with the ore mineralization of many ore deposits from the hypothermal to the epithermal or xenothermal classes on which there are quantitative data is seldom more than is lost by the associated wall alteration, is supported by much available evidence. But we shall have to exclude those deposits in pure limestone where visual inspection shows a

concentration of exotic silica the source of which may be less obvious, although in some cases altered alumino-silicate rocks are known to occur in the basement.

Lindgren gives data (11, p. 535–542, 549–562, 648) that indicate a loss of silica in the walls and a gain in the veins. Schwartz's general paper (24) on alteration suggests no gain or loss of silica during general wall rock alteration.

Studies of the "porphyry" copper deposits by various authors since 1904 at Bingham, Utah (29), Ely, Nevada (28), Miami (15), Ray (15), Castle Dome (14), Ajo (8) and Bisbee (16), Arizona, provide data that are remarkably consistent in suggesting no gain in silica upon alteration (see paired analyses, Table I). This is surprising, particularly when one considers the variation in the types of alteration of some of the "porphyry" deposits and the fact that the sampling was done with different objectives in mind. Then, too, in only a few cases were bulk specific gravity determinations made. The lack of such determinations has not, however, increased doubt because the density of the ore in all cases except Bisbee appears to be about the same or less than the original rock. Except at Bisbee, this is because little if any iron has been added to the ore, indeed, in several cases it appears to have been subtracted and, further, because the porosity generally is greater than the solid, primary unaltered rock.

During the discussion of his paper on Climax, Colorado, at El Paso, October 1953, Fred Howell stated that he thought most of the elements except the valuable metals but including silica were merely rearranged by the alteration. Kenyon Richard in a personal communication in 1953 stated that he believed there was no gain or loss of silica at Silver Bell, Arizona. At Climax, Colorado, Santa Rita, New Mexico and Majdanpek, Serbia, the juxtaposition of major blocks of hypogene argillic and other alteration to smaller, mostly interior, plugs and/or lenses of high quartz rock is suggestive and resembles the particular relationships along veins.

Spencer (28, p. 58) states in his detailed analysis of the metamorphism and alteration at Ely, "In general, then, the metasomatic alteration of the porphyries involved no important loss or gain in silica."

Gilluly (8, p. 82) in discussing similar problems at Ajo, Arizona, says,

"From this table (Table 7) it can be seen that, aside from a slight increase in silica the only considerable changes in the primary rock-forming constituent brought about during the alteration of the quartz monzonite to a copper ore were a considerable loss in lime and a gain in potassa and probably in alumina."

No bulk specific gravity is given for the fresh rock. In "porphyry" coppers this is normally higher than the ore and if so at Ajo could reduce or erase the slight gain in silica.

Paige (13) when discussing the alteration at Tyrone, New Mexico, states (p. 27–28),

"No analyses of the rocks of this district have been made. This course was decided upon after careful consideration of the results in other places where al-

most precisely similar associations or rocks and metamorphic processes prevail. It has been shown that in such districts potash has been introduced while soda, lime and magnesia and alumina were removed; also that sulphur has been introduced while the proportion of quartz apparently remained about stationary."

Later (p. 28) he adds,

". . . as the intensity fractured zones contain great quantities of visible vein quartz and afford evidence that the walls or numberless veins were replaced by quartz *it does not seem possible to believe* (writer's ital.) that the silica present in the original rock at any particular level was sufficient to account for the quartz. . . ."

Paige, nevertheless, points out the considerable loss of silica implied by the widespread sericitization. On page 27 he gives an analysis (Table 1, No. 20) of a quartz sericite vein. This analysis does not differ significantly from that of an average granite (Table 1, No. 18) or an average quartz monzonite (Table I No. 19. Both occur and have been altered in the ore zone) except that lime, magnesia, and soda have been lost. Note that in this case not even potassa appears to have been added! He mentions (p. 37) that kaolin (or hallosite) commonly occurs even below the zone of chalcocite enrichment. This means desilication, and possibly argillization will be found to be extensive, as has been the case at other "porphyry" deposits.

The limited data available that permit a comparison of the enriched ore or supergene zones with protore or hypogene zones suggest that little or no important change in the proportion and quantity of the oxides has taken place. The data given by Ransome (15, p. 159) on Ray and Miami, Arizona, indicate that the hypogene altered rock suffered little change from supergene processes save an enrichment of copper.

The abundant pertinent data on veins will not be summarized here, but in addition to those on the Mother Lode of California there are many that bear significantly on the problem. The walls of quartz veins may be strongly carbonatized. Examples (Schwartz, 24) occur at Ophir, California; Tonapah, Nevada; Cripple Creek, Colorado; Breckenridge, Colorado; and Oatman, Arizona. As is well known, walls in addition are commonly thoroughly chloritized and epidotized, and these processes mean loss of silica. The process of sericitization does also, but sericite is generally associated with the gain in free quartz in the same fabric.

Unpublished studies by Schmitt and chemical analyses by Lawson Entwistle (Table I, analyses 1 and 2) of samples of walls and veins of the Ground Hog mine, New Mexico, indicate that the chloritization, epidotization, and carbonatization of the granodiorite porphyry walls resulted in a loss of silica amounting up to 25 percent. The gangue of the vein is principally quartz. There is only minor quartz or silicates, however, in the ore in the lower levels of the mine where the walls are largely limestone and a smaller volume of granodiorite dikes.

Some of the minerals commonly found as metasomes in wall rock alteration and their average silica content are listed below.

Mineral	SiO_2 %	Ref.	Mineral	SiO_2 %	Ref.
Bauxite (supergene only ?)	00.0		Magnetite	00.0	
Biotite group	±37.1	2	Montmorillonite	49.40	17
Carbonate group	00.0		Pyrite	00.0	
Chlorite group	±28.5	2	Pyroxene group	± 51.5	2
Epidote group	±37.8	2	Quartz	100.0	
Garnet group	±36.4	2	Sericite	± 45.4	2
Kaolinite	46.35	2	Tourmaline group	± 36.7	2

The silica content according to Daly (5) of the average basalt is 49.06%, monzonite 56.1%, diorite 56.12%, andesite 59.59%, granite 70.18%, and rhyolite 72.77%.

Thus most of the minerals that normally occur as metasomes of the common igneous rock walls, chlorite, epidote, carbonate, sericite, biotite and clay have a lower silica content than the common igneous rocks, even lower than the basalts. There can be a gain in silica only if quartz is introduced or if low silica palasomes are replaced by high silica metasomes or if there is a diminution of volume or an increase in porosity.

The most prominent minerals that normally replace limestone walls, jasperoid, and garnet and pyroxene, of course, indicate a local gain in silica in proportion as the walls are pure limestone or dolomite. In the writer's experience epidote uncommonly replaces pure limestone. The work of Allen and Day (1) and Fenner (6) at Yellowstone Park indicates that there the free silica in the veins is derived from wall rock alteration processes.

In the case of the contact pyrometasomatic or tactite zones of silicates, the common lack of detailed studies of the sedimentary rock column with accompanying rock analyses, and lack of large-scale detailed mapping of the ore zone, with analyses of the rocks before and after metasomatism, leads to an exaggerated view of the amount of limestone present, and, therefore, the volume of ground that gains silica through garnetization and other silication. At the same time the magnitude of the silica lost by the epidotization and chloritization of the local aluminous rocks, including the "central" intrusive itself, is overlooked. Further, the porcellanite beds just outside of the tactite zone are commonly called silicified limestone beds when actually they are only baked shale or shaly limestone beds. No silica is gained by these. They are *metamorphic* products only. This all adds up to perhaps in some cases as much as a 100 percent error in estimating the amount of silica gained from other than a local source.

The quantitative data given by Schmitt (19) on the tactite zone at Hanover, New Mexico, indicate that the aluminous rocks have lost substantial amounts of silica and the carbonate rocks have gained silica. Although the net gain of silica in the zone was estimated to be 165 percent, this was exceeded by the gain in iron. Since large blocks of adjacent intrusive are chloritized and epidotized and a thick shale is known in depth, the writer feels that there is a basis for the belief that all the silica may be of local derivation and that only iron, zinc, and sulphur were imported in quantity into the zone. Other contact-pyrometasomatic deposits have associated rocks that have lost silica through alteration. This aspect of the problem would seem to deserve further investigation.

So far, the writer has refrained from inferring too strongly that the silica present as visible secondary quartz and in new silicates represents silica lost locally through the metasomatic or alteration processes. But the inference is nearly conclusive in the case of the "porphyry" coppers, since in the rock fabric the distance between blocks that have lost silica and those that have gained it is often measured in feet or in inches only. Further, the mineralized porphry blocks are more or less homogeneous and equidimensional. The quantitative work on the Hanover, New Mexico, tactite zone suggests a similar picture of a block entity except that the change in the distribution of silica was done at higher temperatures or at least in a limy environment and silica was stable only in new silicates.

In the case of veins, a genetic relationship between the loss of silica in the walls and gain in the main channels seems probable, particularly in the light of the quantitative work of Knopf (9), Lovering (10) and Sales and Meyer (18). At this time only an outline of the apparently important aspects of the problem can be considered. These include: (1) the structure of the average vein, (2) the nature of the alteration, (3) the paragenesis of the minerals, and (4) the character of the fluid agents and their source and their role in the local distribution and redistribution of the elements.

(1) The intimate structure of the average vein, perhaps excluding the especially deep-seated ones, appears to be essentially as follows: It is generally marked by a central fault or channel, which in the beginning at least, is defined by a gouge that is not absolutely impermeable. Immediately adjacent to this is a permeable breccia commonly limited outwardly by slips. The walls adjacent to these are broken in a decreasing degree outward. Subsurface experience with unmineralized faults indicates that the ground water encountered flows freely through the breccia, less freely through the broken walls, and that the gouge is saturated with moisture. Fault zones may act as dams to fluids moving transversely, but as conduits par excellence parallel to their extension, unless and until the walls and breccia are reduced by alteration to soft minerals and/or are choked by deposition.

Macroscopic and microscopic evidence indicates that most vein faults are reopened many times during mineralization. The gouge is hardened by the action of the circulating hot fluids and finally, along with much or all of the breccia, is replaced by quartz. As mineralization progresses the walls become more impervious and the central zone more pervious as the development of brittle quartz, along with re-faulting, results in a more and more concentrated and open channel. Before the deposition of the sulphides, then, the main channel is a quartz breccia and this channel is commonly efficient as a conduit even after most sulphide deposition has taken place, for the sulphides in turn are commonly brecciated. This is taught by experience with wet mines.

(2) The basic type of alteration is characterized chiefly by the development of chlorite, epidote, carbonates and clay. These minerals, of course, tend to localize in the walls, i.e., the less strongly broken ground. The more acid type of alteration, generally characterized by the development of sericite and quartz, but commonly also by carbonates, tends to localize in the more open

ground adjacent to, and including the main channel. Open spaces are favored by quartz deposition, but carbonates are not uncommon there. Incidentally, the above distribution is also illustrated in the finer fabric of some of the "porphyry" coppers. Silica is lost from the interior of the breccia fragments and quartz is deposited in the boundary cracks and interstices. This must be inferred from the paired analyses, since a given quartz veinlet obviously represents a local gain in silica.

(3) Paragenetic studies show consistency in the sequence of deposition of the vein minerals. As a rule most of the quartz and silicates precede the sulphides at least at a given spot. The sulphides fill cracks in the quartz and silicates and commonly replace them. The work of Sales and Meyer indicates that a given stage in the paragenesis is reached at different times at different places. It also strongly suggests that the quartz of the vein is deposited as the wall is altered and loses silica. If this is the case the sulphides seem to represent a stage clearly later than the general wave-like process of alteration. Many writers have remarked that the wall alteration appears to be earlier than the sulphide deposition. Even so, this belief perhaps needs more study and verification. Sulphides generally cut and/or replace such minerals as epidote, chlorite and even garnet and other silicates in tactite zones.

(4) The possible nature of the mineralizing fluids is of perennial interest to many. Some progress is being made. When red rocks are mineralized in the vicinity of sulphide ores they are generally bleached. At times this reaction is sufficient to completely oxidize the incoming sulphur. Copper is then commonly deposited in the native state; the sulphur gives rise to the sulphate anion.

The fluids that commonly alter the walls, and those that later give rise to the sulphides, seem to be reducing ones. The exceptions include the early stages in pyrometasomatic deposition when ferric silicates are deposited, and the near surface oxidizing conditions at hot springs where H_2S is present.

Regarding the hydrogen ion concentration: The fluids whatever their original nature must soon become alkaline or more alkaline when they encounter and break down the silicates of igneous rocks. The common presence of carbon dioxide and water in vacuoles in the minerals and the formation of carbonates suggests that H_2CO_3 has been present and has had its usual destructive effect on silicates and quartz. Large amounts of sodium and potash are, of course, liberated and transported. Shand (25, p. 193) thinks that the environment of a consolidating igneous magma must be alkaline because of the predominance of these strong bases. Graton (7) thinks that the fluids are alkaline when they leave the "magma." Hot spring and fumarolic studies show, nevertheless, that near surface, apparently largely unmodified volcanic emanations are acid. These are often observed as fumeroles and vapors from freezing lava. The oxidation by the atmosphere of alkaline hot spring waters carrying H_2S results in shallow acid waters. Thus, it would seem that the introduction of an excess of oxygen, whatever its source, into fluids carrying hydrogen sulphide often results in an acid and/or oxidizing condition. There is some justification perhaps for believing

that ore fluids if oxidized become acid. The volcanic emanations may be acid because of the excess of oxygen available at high temperature from carbon dioxide and water gas. The presence of the strong acids, chlorine and fluorine, in one form or another further decreases the pH. The brines in the vacuoles in sulphides tested by Newhouse (12) were neutral.

Presumably the fluids must be in a fairly dense form or the wholesale transfer of ions is not likely to occur during the alteration process. This may be a density induced by pressure at great depths (Smith, 27). Or at shallow depths it may be a "true liquid." The work of Newhouse (12, p. 419–436) appears to give a clue as to the chemical and physical nature of the fluids, although doubt may be felt as to hypogene nature of the alkali brines found in the vacuoles because of the common occurrence of similar brines in many deep rocks. But, as will be noted later, these brines are to be expected in ore fluids on the basis of a hypothesis to be proposed.

If we can assume that the silica of the veins is indeed largely of local origin we are free from certain limitations on the nature of the fluids, at least those entering the zone of deposition from the unknown ultimate source.

When summarized and generalized the data on paragenesis and mineralogy of the wall rock alteration suggest that the early fluids, at least, generally contain water and carbon dioxide, and, since they are commonly reducing in nature and contain sulphur—for local iron is often converted to pyrite—they may also contain hydrogen sulphide. As the reaction proceeds the fluid if not previously alkaline soon becomes so because it becomes charged with K and Na as well as SiO_2. These elements in whatever their chemical form and ionic balance advance toward the open channel and some CO_2, H_2O and H_2S is used up. The early wall rock fluid agent is definitely silica seeking. But, by the time it reaches the vein it is silica depositing. This in itself separates it in time from the fluid of the main channel *of sulphide time* for this fluid is silica dissolving and, of course, sulphide precipitating. If the inferences of Newhouse's work are to be accepted, this latter fluid is a strong, neutral calcium and sodium chloride brine with not much else in it, at least after the metals are deposited. Any free CO_2 may have been used up by reaction with the walls of the vacuole. Ample time is available for this. It has been reported that H_2S occurs in the vacuoles of certain sulphides.

It seems fair to call upon ionic transfer for much of the redistribution of material in the vicinity of the main channel, but presumably for egress of primary fluids and exit of the modified or spent fluids we are forced to call on convection if the fluid is sparse in metals a great volume of it must pass through the zone. But if it should be gaseous on egress to a "pond" of liquid, little or no exit of dense watery material could suffice. This could be composed largely of saturated steam. The soda lost from the walls with some lime could combine with free chlorine and stay in a stagnant "pond" or in part be deposited high in the vein in zeolites, as at Yellowstone Park.

The mode of circulation of the convective part of the fluids should be considered. Since fissures tend to tighten up with depth the conduit may well be restricted in depth. Higher, the fluids can soak and deeply penetrate the walls as shown by fumarolic-hot spring studies, but with varied

velocity, the greatest being in the vicinity of the channel. Toward the last the flow may be largely restricted to the broken quartz of the vein. Alternately the primary fluid could occur as a saturation of the country rock and work its way by small cracks into the more open zone along the channel and then escape upward after having done its work in a more or less stagnant "pond" of water. That a whole country rock can be saturated by hot fluids has been observed around fumaroles and steam wells.

The above data pro and con almost of themselves point the way for one or more hypotheses. First, an hypothesis seems feasible that the wall rock alteration is isolated from the distinct sulphide stage and, further, may be discussed independently of any belief as to the ultimate origin and path of egress of the primary fluids. One might say that essentially a picture is presented of a broken block of ground related to and bordering a central channel. This becomes saturated with a dense fluid which may be a condensate from the primary fluids or a pocket of connate, sea or meteoric water or even, if one insists, a dense hydrous fluid from below.

In any case, it becomes a gigantic "pot of stew" fed by fresh CO_2, superheated H_2O and H_2S. In general the silica, alkalies and commonly the alkaline earths are cooked out of the walls. The silica lodges in the open spaces as a scum so-to-speak. The potash is commonly most stable as a sheath bordering and/or associated with the quartz. The sodium and calcium may in part become tied up with Cl from the primary fluids. There is, of course, much variation in the detail of occurrence. Carbonates at times are more stable in the veins than in the walls or may occur in both.

It seems difficult to explain the sudden change in the fluids from silica-seeking in the walls to silica-depositing in the more open spaces. Possibly one must call on mass action and super-saturation to explain the sudden dumping, or one must postulate a diagonal path for the fluids converging upward from the walls to the vein rather than a direct horizontal one from wall to vein. The silica and silicate corroding fluids of the sulphide stage may be the result of a greater concentration of the raw corrosive primary elements in the main channel with little chance of their neutralization by fresh silicates. By this time the source of active fluids may have advanced or retreated or merely been blocked off from the walls because of previous alteration and deposition. The corrosion of the quartz is not difficult to understand, but the cause for the deposition of the sulphides from a brine solution seems unclear unless it is the result of supersaturation, mass action and cooling. Newhouse has shown that hot brines *corrode* galena. Further consideration of this complex problem must be left for a later date.

It seems as if the above hypothesis may apply to the "porphyry" coppers as well as to veins and even with modifications to the pyrometasomatic deposits. Here there is generally an early oxidizing and possibly acid stage when the heavy silicates are formed by silica at least in part derived from the alteration of alumino-silicate rocks and by lime from limestone. The "epithermal" deposits appear to fit in with this scheme also but here meteoric water may be a chief agent (Schmitt, 21, 22, 23).

The above framework of facts, probabilities and inferences will lend itself

to alternate hypotheses, but these must be dealt with at a later time. Many objections may be made: (1) There are said to be veins of quartz that show no or no appreciable associated wall rock alteration at least for the exposed depth of observation. Although the known facts of the transfer of silica suggest to this writer that in general the transfer is more restricted than has been generally assumed to be the case, nevertheless, it would seem that silica in the colloidal form at least should be stable and mobile enough to travel as far as a water column extends along an open structure. In near surface zones this could be as deep as ground water penetration which in turn could be as deep as an open channel can persist. This may be measured by thousands of feet. Heat in depth can be absorbed by quenching and as stated by Fenner generated steam cannot be expected to push against the water as a piston. It can bubble up through it and through cavitation lighten the column and partially off-set gravity.

If an extreme may be assumed, a replacement vein in alumino-silicate rock with no alteration of the walls—this may be a purely hypothetical case—the amount of silica released by replacement of breccia and gouge by sulphides, could amount up to, say, 70 percent of the volume of the vein if all the original vein material is replaced. A common case of replacement is a vein of abundant quartz and carbonate with sulphides. Only the sulphides and CO_2 need to have been added.

There are cases where quartz and jasperoid with associated ore minerals replace limestone. It is the writer's impression, however, that the amount of silica gangue in limestones is conspicuously less as a rule than where the walls are primary alumino-siliceous rocks. Commonly alumino-siliceous rocks are not far away. In many cases they are the basement rocks.

(2) The problem of why the sulphides and even the silica precipitate at all may be more difficult than is usually assumed in the light of the known low rate of heat transfer in rocks. If it is mostly the result of heat transfer to the walls how is the heat lost at a sufficiently rapid rate? The alteration processes are possibly endothermic? In the "epithermal" zone meteoric water is available for the removal of heat. A process that increases the sulphide ion, such as a migration of H_2S from the walls to the more open vein may cause precipitation of sulphides through mass action.

The writer has found that upon making as objective an analysis as possible of the various types of ore occurrence he usually comes up with a relatively short list of elements that indubitably are foreign to their environment. That is, if the question is asked which elements present could not possibly have been derived from the local environment one arrives at the following list: C, S, Cl, F, B, As, Sb and the other heavy metals. Even the metals can be suspect when the walls contain them. Normally some H and O are imported in H_2O, CO_2 and H_2S molecules. When the walls contain original carbonate, secondary carbonate minerals are commonly more prominent in ore deposits, so under these conditions some or all of the CO_2 can be derived from the local environment. As noted earlier the alkalies and alkaline earths and apparently silica can in places be accounted for as having come from nearby blocks of alterated alumino-silicate rocks. The final list, then, that represents

the normally definitely imported elements is limited to H, O, C, S, Cl, F, B, As, Sb and the other heavy metals.

The first three elements plus nitrogen and helium are prominent in the atmospheres of the planets and sun often as the compounds CO_2, H_2O, NH_3 and CH_4 (Smart, 26, p. 73–88). Sulphur and chlorine (particularly as $FeCl_2$) are found in meteorites as are some of the metals (excepting lead and zinc) and many of the other elements. The composition of the average stony meteorite represents a peridotite. No granite-like stone is known. It is generally believed, of course, that the meteorites represent a disrupted planet and that the Earth itself may be compared with a great meteorite.

When one considers the volcanic and fumarolic emanations and hot springs it is found that particularly prominent and reoccurring again and again are H, O, C, N, S, Cl, F, B, As and to a minor extent the metals. At the lower temperatures the commonest compounds are H_2O, CO_2, CH_4, NH_3, H_2S, SO_2, Cl_2, F_2 and AsS. This leads to the strong suggestion and inference that volcanic phenomena basically are cosmic in nature as suggested by Tschermak (30). The tie-in between the "volcanic emanations" and ore deposits would seem on firm ground even if along the trail of genesis magmation phenomena intervene.

The most prominent and effective agents in wall rock alteration whether in alkaline, acid oxidizing or reducing environments appear to be H_2O, CO_2 and H_2S. These three compounds or elements or compounds derived from them through various temperatures and reactions happen to be those most prominent in the volcanic phenomena. It should be further noted that most rocks (Clarke, 4, p. 276–281) when heated give off gases of which CO_2 and H_2 are generally the most prominent and H_2S is common. The H_2 is from H_2O originally in the rock that has been decomposed by the heat and by the oxidation of elements in the rock chiefly ferrous iron (4, p. 281).

The iron so common to most ore deposits (excepting the "epithermal" type) can perhaps be best explained as derived from earth iron in the form of $FeCl_2$. A discussion of the difficult problem of the transfer of the metals must be postponed.

CONCLUSIONS AND INFERENCES

1. The silica represented by the quartz and silicates of many if not most ore deposits as varied as "porphyry" coppers, "epithermal" and deeper-seated veins and pyrometasomatic deposits logically can be said to have been derived from the alteration of the adjacent walls.

2. The data point directly to the egress of H_2O, CO_2, at times boron and indirectly to H_2S during the stage of early wall alteration and quartz deposition in the open spaces, and to the egress of H_2O, H_2S, CO_2, the metals, always Cl, and often F, As, and Sb during the sulphide stage.

The early wall rock alteration stage witnesses a loss of silica, the alkalies, and in places the alkaline earths. Only alumina and a minor amount of silica plus commonly some iron, carbon dioxide, sulphur and water appear to be relatively stable in the walls. The vein gains silica or carbonates, and potash,

commonly in sericite rarely in adularia, accumulates as a selvage or sheath bordering the quartz masses. The soda is largely carried off, but a minor amount remains with chlorine as brine with some $CaCl_2$ in vacuoles in the quartz and sulphides. Should the reaction in the walls go to an unlikely conclusion it would seem that the end product should be a low silica clay of the kaolin group which contain no alkaline earths or iron as are found in the montmorillonite group. The writer knows of no case, however, where the alteration has progressed to minerals of the bauxite group which contain no silica at all.

The sulphide stage occurs after the deposition of most of the quartz (and carbonate ?) of the main channel and generally after these minerals have been broken by renewed faulting. This is commonly a stage of quartz (and carbonate?) instability when the quartz (and carbonate ?) may be etched and replaced. The fluid agent may be largely a strong brine with minor H_2S and CO_2. The brine could be derived from the soda and lime lost from the walls and the chlorine from the primary fluids.

3. The common setting may be described as one of a "pot of stew" continually heated, seasoned and replenished by the normal "volcanic emanations" accompanied by the metals. A "scum" of quartz and sericite fills the more open country. Such an environment can be visualized for the "average" veins including "epithermal" veins, the "porphyry" coppers, and with modification for the pyrometasomatic deposits.

4. The amount of watery fluid entering the zone of activity may be much smaller than usually visualized. A pocket or "pond" of dense fluid may occur in a block of open structure. This may be a condensate, connate, sea or meteoric water trapped in and along the structure. The critical and identified agents enter the field, are modified, perhaps spent, and possibly only saturated steam with H_2S and CO_2 is boiled off. No feeding column or exit column of dense fluid or liquid need be postulated. This is essentially the environment inferred (Allen and Day, 1 and Fenner, 6) from the facts at Yellowstone Park and now said by White (31, 32) to exist at the metal depositing fumaroles and springs at Steamboat Springs, Nevada.

5. In earlier papers Schmitt (20, 21, 22, 23) suggested that the chief agents active in wall rock alteration and ore deposition in the pyrometasomatic tactite zones, the "epithermal" deposits and the "porphyry" coppers were similar to the volcanic emanations, and indeed are identical. The present analysis suggests a similar environment for the *average vein*. These emanations are characterized chiefly by superheated steam, CO_2, H_2S, Cl_2, F_2, CH_4, NH_3 and the metals. These compounds largely disassociate in part or wholly at high temperatures to the simple elements: H, O, C, N, S, Cl and F and the metals. The first six elements are prominent in the universe and meteorites and are prominent elements of the Earth. $FeCl_2$ is common in meteorites and therefore probably in the Earth and may account for the abundant iron of many ore deposits.

SILVER CITY, NEW MEXICO,
June 10, 1954

REFERENCES

1. Allen, E. T., and Day, A. L., 1935, Hot springs of the Yellowstone National Park, Carnegie Inst.: Washington, Pub. 466.
2. Bayley, W. S., 1917, Descriptive Mineralogy, D. Appleton & Co., New York.
3. Beveridge, W. I. B., 1951, The Art of Scientific Investigation, W. E. Norton & Co., New York.
4. Clarke, F. W., 1924, The data of geochemistry: U. S. Geol. Survey Bull. 770.
5. Daly, R. A., 1933, Igneous Rocks and the Depths of the Earth, McGraw-Hill Book Co., New York.
6. Fenner, C. N., 1936, Bore-hole investigations in Yellowstone Park: Jour. Geol., vol. 44, no. 2, pt. 2, p. 225–315.
7. Graton, L. C., 1940, The nature of the ore making fluids, Econ. Geol., vol. 35, Supp. No. 2.
8. Gilluly, J., 1946, The Ajo mining district, Arizona: U. S. Geol. Survey Prof. Paper 209.
9. Knopf, A., 1929, The Mother Lode system of California: U. S. Geol. Survey Prof. Paper 157.
10. Lovering, T. S., 1941, The origin of the tungsten ores of Boulder County, Colorado: Econ. Geol., vol. 36, p. 229–279.
11. Lindgren, W., 1933, Mineral Deposits, McGraw-Hill Book Co., Inc., New York.
12. Newhouse, W. H., 1932, The composition of vein solutions as shown by liquid inclusions in minerals: Econ. Geol., vol. 27, p. 419–436.
13. Paige, S., 1922, Tyrone district, New Mexico: U. S. Geol. Survey Prof. Paper 122.
14. Peterson, N. P., 1951, Geology and ore deposits of the Castle Dome area, Gila County, Arizona: U. S. Geol. Survey Bull. 971.
15. Ransome, F. L., 1919, The copper deposits of Ray and Miami, Arizona: U. S. Geol. Survey Prof. Paper 115.
16. ——, 1904, Geology and ore deposits of the Bisbee quadrangle, Arizona: U. S. Geol. Survey Prof. Paper 21.
17. Ross, C. S., and Hendricks, S. B., 1945, Minerals of the montmorillonite group: U. S. Geol. Survey Prof. Paper 205B.
18. Sales, R. H., and Meyer, C., 1948, Wall rock alteration at Butte, Montana: Am. Inst. Met. Eng., Trans., vol. 178, p. 9–35.
19. Schmitt, H., 1939, The Pewabic mine: Geol. Soc. Am. Bull., vol. 50, p. 777–817.
20. ——, 1948, The contact pyrometasomatic aureoles: Am. Inst. Met. Eng., vol. 12, no. 3.
21. ——, 1950, The fumarolic-hot spring and "epithermal" mineral deposit environment: Colo. School of Mines, vol. 45, no. 1B, p. 209–229.
22. ——, 1950, Origin of the "epithermal" deposits: Econ. Geol., vol. 45, p. 191–200.
23. ——, 1953, Comments on the "porphyry" copper deposits: Econ. Geol., vol. 48, p. 416–417.
24. Schwartz, G. M., 1939, Hydrothermal alteratioh of igneous rocks: Geol. Soc. Am. Bull., vol. 50, p. 181–237.
25. Shand, S. J., 1949, Eruptive Rocks, Thomas Murby & Co., London.
26. Smart, W. M., 1951, The Origin of the Earth, Cambridge Univ. Press.
27. Smith, F. G., 1953, Review of the physico-chemical data on the state of supercritical fluids: Econ. Geol., vol. 48, p. 14–38.
28. Spencer, A. C., 1917, The geology and ore deposits of Ely, Nevada: U. S. Geol. Survey Prof. Paper 96.
29. Stringham, Bronson, 1953, Granitization and hydrothermal alteration at Bingham, Utah: Geol. Soc. Am. Bull., vol. 64, p. 945–992.
30. Tschermak, G., 1877, Sitzungsb. Akad. Wien, vol. 75, p. 151.
31. White, Donald, 1953, Origin of the ore-forming fluids: Discussion panel, Am. Inst. Met. Eng., Los Angeles, Feb.
32. ——, 1952, Three dimensional picture of Steamboat Springs, Nevada: Geol. Soc. Am. Bull., vol. 63, no. 12, pt. 2, p. 1311–1312.

EXPLOSION PIPE IN TEST WELL ON HICKS DOME, HARDIN COUNTY, ILLINOIS[1]

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CONTENTS

	PAGE
Abstract	891
Introduction	891
Stratigraphy	892
Structure	893
Crypto-volcanic affinities—explosion breccias	895
Mineralization	897
Radioactivity	899
Petrographic details	901
References	902

ABSTRACT

In 1952, St. Joseph Lead Company drilled a well on the apex of Hicks Dome in Hardin County, Illinois, primarily to explore for oil or gas, and with the objective of testing the St. Peter sand horizon, which had not been reached in a previous well on the flank of the dome. A normal sequence of formations was encountered down to 1,600 feet, but at about that depth the drill entered a confused brecciated zone, which persisted to the bottom of the hole at 2,944 feet. This is interpreted as one of the explosion type breccias, or diatremes, common in this Illinois-Kentucky area, as well as in nearby Missouri. A correlation of formations between this and the earlier Fricker well is presented. It is suggested that Hicks Dome is an incipient or uncompleted cryptovolcanic structure.

Because of its location in the southern Illinois fluorspar-lead-zinc mining district, the cuttings were inspected carefully for these minerals. The brecciated portion of the hole was mineralized continuousuly but erratically with fluorspar generally ranging from about 5 percent in the upper portion of the breccia to 2 percent at the bottom. This is much deeper than previously known in such amounts in the area. Parallel with the fluorspar content and similarly diminishing downward is an abnormal radioactivity characterized by 0.029 percent eU in the upper part of the breccia zone. The possibility is suggested that this could have been picked up from the formerly overlying New Albany, or Chattanooga, shale.

INTRODUCTION

THE information given herein has been released through the courtesy of the St. Joseph Lead Company in the belief that it is of more than ordinary scientific interest, even though it seems to have no immediate practical value.

Henry Hamp, Jr. No. 1 well was begun August 25, 1952, and abandoned November 27 the same year at 2,944 feet. It is situated three-fourths of a

[1] Presented before the Society of Economic Geologists, Toronto Meeting, November, 1953.

mile northwest of an earlier test known as the Fricker well, which reached a depth of 3,207 feet. Lost circulation, due to fractured, cavernous, and brecciated ground, caused extensive delays in drilling. Many of the common correctives used in oil-well practice were applied, the most effective being a combination of high early cement and calcium chloride. Approximately 30 percent of the hole had to be re-drilled through this or other cementing material.

In order to watch the results on the ground, Emery and Meyer were detached from the Geological Staff of the St. Joseph Lead Company at Bonne Terre, Missouri, and spent alternate weeks at the well site from August 25 to October 27. Thereafter, the cuttings were studied on weekly visits. Cuttings were examined by binocular microscope as drilling progressed; insoluble residues were prepared and studied later. A few sidewall cores obtained at the close of drilling were studied in thin section.

STRATIGRAPHY

Formations of Pennsylvanian and Mississippian age form concentric bands around Devonian limestones in the center of Hicks Dome (Fig. 1). The oldest visible formation is the New Albany shale (Mississippian-Devonian). Loess and a heavy residual chert clay obscure the contacts of the older formations in the center of the dome.

Following is a comparative section of the Fricker and Henry Hamp, Jr. wells, as interpreted by Emery and Meyer:

Formation	Fricker Well Depth	Fricker Well Thickness	Henry Hamp Well Depth	Henry Hamp Well Thickness	Ratio
Upper Devonian					
New Albany Shale	83	71	—	—	
Alto Formation	100	17	—	—	
Middle Devonian					
Lingle Limestone	135	35	—	—	
Grand Tower Limestone	323	188	—	—	
Dutch Creek Limestone	347	24	—	—	
Clear Creek Limestone	816	469	275	275+	
Lower Devonian					
Backbone Limestone	858	42	300	25	.60
Bailey Limestone	1482	624	795	495	.80
Silurian					
Moccasin Springs Limestone	1607	125	890	95	.77
St. Clair Limestone	1655	48	930	40	.83
Sexton Creek Limestone	1669	14	942	12	.86
Edgewood Limestone	1775	106	1000	58	.55
Ordovician					
Maquoketa Shale	2016	241	1225	225	.94
Kimmswick Limestone	2110	94	1287	63	.67
Decorah-Plattin Limestone	2895	785	1815	528	.67
Joachim Dolomite	3207	312	2057?	242	.77?
Dutchtown Formation		99+ T.D.	?		
St. Peter Sandstone					
Knox Dolomite (Includes Missouri Section Derby-Doerun up through Jefferson City)					

Cuttings show the Hamp well to be collared in the Clear Creek formation approximately 500 feet stratigraphically below the New Albany shale. It bottomed in the Ordovician in what should be Knox dolomite, but because of intense brecciation that has confused lithologic units throughout 1100 feet of hole, the exact stratigraphic location is unknown.

The last definite contact was the Decorah-Plattin-Joachim at 1815 feet with a tentative Joachim-Dutchtown placed at 2,057 feet. The upper formation contacts were readily picked and compared reasonably with the log of the Fricker well (1)[2] although the dolomitic content of pre-Joachim formations was less than that described in the Fricker.

The first traces of St. Peter type sand (2) were encountered at 1,815 feet, and sand grains were found in varying quantities to the bottom of the hole. A residue study was made from 1,970 to 2,944 feet to find evidence of pre-St. Peter sand types. All sand grains studied were of the same nature, i.e., rounded, pitted, frosted, and of various sizes. They lacked evidence of secondary enlargement or great angularity, which are supposedly indicative of pre-St. Peter sediments (3).

Brecciated zones showed a wide variation in the lithology of included rock particles. Pieces resembling Maquoketa shale were found 1,000 feet below the base of that formation and adjacent to fragments of unknown source. St. Peter type sand was found to cover more than twice its normal range (Joachim-Everton). Thin sections of cores showed agglomeration of sandstones, quartzites, limestones, dolomites, and shales. No primary igneous particles were positively identified. The question of the origin of this breccia is discussed in detail later.

Two breccia bodies of this type have been noted in the immediate vicinity. Both of these structures have been so altered as to obscure greatly their original nature. All the igneous matrix has been replaced by carbonate with the exception of rare apatite.

STRUCTURE

Hicks Dome (Fig. 1) is a structural and physiographic high covering approximately 100 square miles in the western half of Hardin County. Quaquaversal dips, some up to 25°, are noted in some 4,000 feet of sediments from the Devonian core to the Pennsylvania flanks. The axis of the dome strikes approximately N 50°W. Circular and radial drainage are the physiographic manifestations of the dome.

Formations measured in the Fricker well ¾ mile S 70° E of the Hamp are consistently about 25 percent thicker than those in the Hamp. The Edgewood and Maquoketa deviate from this ratio, but, if taken as one, show the same relationship as other formations. As the Fricker well was drilled on the flank of this structure and the Hamp essentially in the center, thickening of formations is believed to be in the main part only apparent. Section A-A[1] (Fig. 2) shows the relationship between these two wells.

The Hicks Dome structure apparently is bounded by peripheral synclines, the most prominent being seven miles to the northwest. Here Pennsylvanian

[2] Numbers in parentheses refer to References at end of paper.

sediments outcrop between exposures of Kinkaid, Degonia, and Clore (Mississippian) limestones, sandstones, and shale. Other synclinal structures are noted to the northeast and east of Hicks Dome. These structures lie outside the bounds of Figure 1.

Three miles to the southeast of the well site the Wolfrab Mill fault transects the dome striking approximately N 50° E. It is a normal fault, being downthrown to the south, and parallels the prominent Peters Creek fault pattern of Hardin County. Parallel to this fault, two to three miles to the northwest, are the Shelby and the Lee faults. Both are normal faults being down-thrown to the south 200 to 400 feet and dip 60° in that direction. The position of

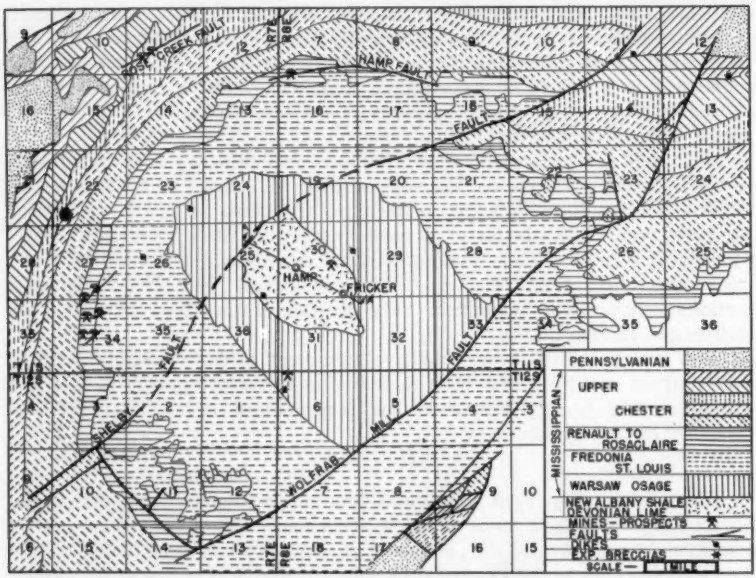


FIG. 1. Geologic map of Hicks Dome area (after Illinois Geological Survey).

these faults is lost under the heavy mantle surrounding the core of Hicks Dome but the straight contact between Devonian and Mississippian sediments to the north of the well suggests that the faults may have united in this area, although this would require a reversal of movement (Fig. 2). The divergence of the two fault systems in the dome area further suggests that faulting is later than the doming.

A broken system of ring faults surrounds the dome. In several of these fluorspar is being, or has been, mined. North of the dome, the Hamp fault is down-thrown approximately 300 feet to the north, and the Rose Creek fault shows a slight displacement to the south. To the southwest, another ring fault

displaced to the south connects the Shelby fault with the Wolfrab Mill fault. Several other ring faults have been noted but not mapped due to poor exposure.

Figure 1 indicates the position and strike of intrusive peridotite dikes. These are but a few of many noted in Southern Illinois and Northern Kentucky. The largest dike in the district is on the Joiner farm, one mile southwest of the well, where an incomplete exposure measures 125 feet in width. All of these dikes show a preferred orientation in the direction of the axis of Hicks Dome, southeast to northwest, suggesting a genetic relationship between them. As encountered elsewhere, they antedate the faulting and mineralization of the fluorspar district.

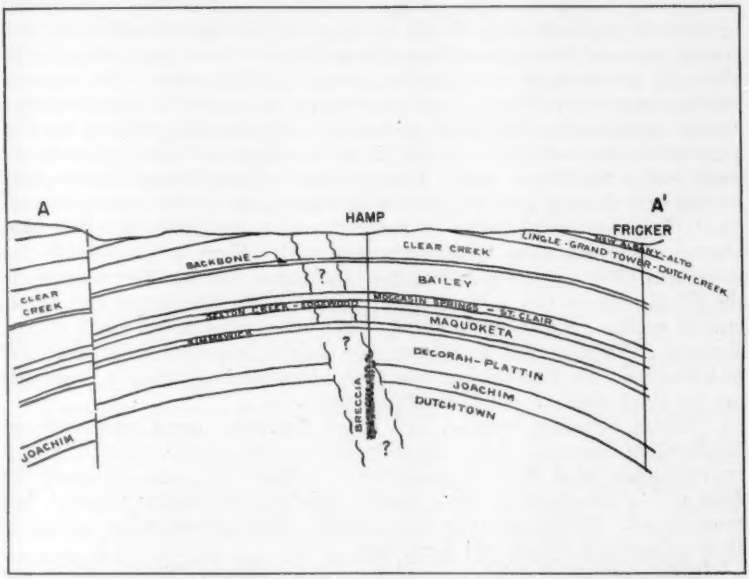


FIG. 2. Cross section showing correlation of Hamp and Fricker wells.

CRYPTOVOLCANIC AFFINITIES—EXPLOSION BRECCIAS

The preceding description, along with some additional features, strongly suggests a kinship between Hicks Dome and a group of well-known but more extreme structures widely distributed in the central United States, and even better developed in Europe. These are collectively compared in a paper by Bucher (4). Among the better examples are Jeptha Knob in north central Kentucky, Serpent Mound in southern Ohio, and Wells Creek basin in north central Tennessee. These structures are respectively about 2, 4, and 6 miles diameter, the peripheries being defined by systems of ring faults, not perfect

but considerably more complete than at Hicks Dome. The corresponding diameter of Hicks Dome, as indicated by the Hamp fault and other portions of the outer ring system, would be 6 or 7 miles. In each case there is a raised central core with about one-third the total diameter of the structure, which would be represented in Hicks Dome approximately by the circle of New Albany shale. In the other structures this core is much broken and faulted. Between the central core and the outer system of ring faults in the other structures is a depressed area forming in some cases a fairly perfect synclinal ring. This is represented feebly at Hicks Dome particularly on the southwest between the two major faults and inside the outer ring faults.

Bucher's explanation of the cryptovolcanic structures, widely, though not unanimously, accepted by the geological fraternity, is that they were formed by volcanic explosions that bored up centrally through the sediments and created waves of disturbance responsible for the concentric synclines and anticlines, all accompanied by violent fracturing and dislocation. This explanation has found favor from the obvious evidence of violent disruption along a central vertical axis with radial diminution of surrounding effects, even in spite of the fact that seldom, if ever, is there evidence of igneous activity directly within the affected area. The situation at Hicks Dome differs notably in that here there is good evidence of igneous action in the form of several basic dikes, part of the system of lamprophyric or peridotitic intrusives that abound in the Kentucky-Illinois fluorspar field. There is also, within the dome area (Fig. 1), one good example of a feature that has been mapped by the Illinois Survey (5) as an explosion breccia. Another occurs just off its eastern margin (Fig. 1) and several others a few miles to the south around Rosiclare. Some of these breccias contain granitic fragments easily ascribable to a source in the Precambrian basement. Possible basic igneous fragments are too much altered for positive identification.

Definite explosion breccias, also called diatremes, occur abundantly in southeastern Missouri, about 100 miles west of the area in question, where approximately 50 of them are described by Kidwell (6); also previously by Rust (7). Two-thirds of these contain definite basic igneous material, but some do not. Within the same area are many basic igneous dikes similar to those of southern Illinois and Kentucky.

In the opinion of at least one of the present authors (Brown) there are excellent reasons to suspect that explosion breccias in this mid-continent area are primarily due to the generation of steam in water-bearing sedimentary formations that were transected by the basic igneous intrusives. Dikes and diatremes, therefore, are merely two different expressions of the same thing. In some cases enough steam was generated by contact with water-saturated rocks to explode, leaving a debris-filled channel, which may or may not contain identifiable remnants of the original dike. This mechanism has been clearly stated recently by Stearns (8). In the case of the Missouri diatremes the cause of explosive action would reside in the presence, at the base of the stratigraphic column, of the Lamotte sandstone, a porous unit of considerable thickness resting directly on the Precambrian igneous basement, and presumably water-saturated. The granitic fragments occasionally found in diatremes

would be either entrained from the immediately underlying basement or would represent the basal conglomeratic portion of the Lamotte.

It is not known whether or not the Lamotte sandstone is present under Hicks Dome, but there is no basis to deny the probability and, if not, some other water-saturated member in the lower Paleozoic section might have served the same function. The possibility of such an origin was, indeed, briefly suggested by Kidwell (6, p. 32) and by Bucher (4, p. 27).

Under the explanation offered above, the depressed ring around the elevated central core of a cryptovolcanic structure probably would be explainable as the result of widespread lateral migration of the water-saturated sandstone into and up the central vent, permitting collapse of the surrounding sedimentary column and the formation of the ring fault system.

On the basis of the evidence and comparisons listed, the authors concur in offering the interpretation that Hicks Dome is an incipient or uncompleted example of a cryptovolcanic structure. Perhaps a reason for its failure to reach the typical end form may lie in the fact that the diatremes and dikes relieved the underlying pressure in easy stages rather than by a single concentrated explosion. One may well speculate as to why the dome remains so pronounced over so broad an area. Does it imply a laccolithic lens of basic intrusive somewhere below, or merely the centripetal migration of some uncemented sandy unit at depth?

MINERALIZATION

Fluorspar mineralization of varying quality was evident in virtually every sample cut in the Henry Hamp, either as breccia filling, veins, incipient veinlets or replacement. Some zones showed indicative fluorspar continuously for 150 feet, one assay yielding 12.8 percent calcium fluoride.

Fluorspar occurs in every color, ranging from clear colorless to opaque purple, the dominant colors being clear green, and purple. Fluorspar in the uppermost zone (310–330) was a clear green and occurred as large chunks free from foreign matter. This was first thought to be a bedded deposit, and sidewall cores were cut in this zone to determine the nature of the material. It was impossible to orient the coring device, but sufficient cores were cut to prove that the deposit was not bedded, hence presumably represented only minor veinlets.

The brecciated zone from 1605 to the bottom of the hole showed mineralization by fluorspar, calcite, quartz, to a minor extent pyrite and even microscopic traces of sphalerite and galena. These minerals occur as the matrix of the breccia, incipient veinlets in the rock fragments, and as replacements of limestone and dolomite. No vertical zoning of these minerals was noted, all three occurring together. The zones with preponderance of fluorspar were assayed. This fluorspar was an opaque purple with minor translucent purple and clear. The significance of the color differences between the upper and lower zones is not known. It may be well to point out that much of the fluorspar in this brecciated zone is very intimately intergrown with the gangue, including siliceous material, and probably would not yield a very good grade of spar.

Thin sections of sidewall cores were made to show the nature of the mineralization and the cause of the brecciation. Apatite, heretofore undetected, was noted in small quantities. Faint flowage structure attributed to movements in the breccia was noted.

Electric well logs of self potential and "micro" type were made by Schlumberger Well Surveying Corporation but were considered completely unsatisfactory over large sections of the hole. Schlumberger attributed this to stray ground currents generated by surrounding mines. We question this conclusion, however, because the nearest mines are three miles distant, 3,000 feet higher stratigraphically and use electricity only in small amount. It seems more reasonable to seek the explanation in or adjacent to the hole itself.

The micro log became completely erratic beyond 1,800 feet. Attempts to overcome this by displacement of drilling mud by fresh water and by use of a new micro logging unit were both unsuccessful. As the sulphides seen in the well were of minor amount, Schlumberger could offer no explanation for the phenomenon since fluorspar and limestone have approximately the same resistivity. However, it is quite possible that substantial amounts of sulphide, especially of iron, may exist near the hole and actually some pyrite shows in several samples and thin sections.

We believe the mineralization to be a replacement and filling of voids in the explosion breccia. There is no reason to believe the mineralization exists only in depth and it may possibly be better nearer the surface. Unfortunately, little is known about mineralization in other structures of this type as none are being mined. It is conceivable that any zone within this structure could contain minable deposits of fluorspar or even of sphalerite or galena.

Below is a tabulation of fluorspar analyses throughout the Hamp Well:

Depth	% CaF_2	Depth	% CaF_2
225– 228	1.9	2250–2275	4.8
315– 321	8.2	2275–2300	3.6
330– 333	7.4	2300–2325	3.1
		2325–2350	3.2
1600–1675	0.3	2350–2365	4.6
1675–1700	2.8	2375–2425	6.3
1700–1725	6.4 Also	2425–2450	6.6
1725–1735	9.4 0.1 Zn	2450–2475	4.6
1750–1760	6.6	2475–2500	2.5
1775–1805	9.2	2500–2525	3.1
1832–1875	4.1	2525–2550	3.4
1875–1900	4.6	2550–2575	2.9
1900–1925	4.3	2575–2600	2.5
1925–1938	3.8	2600–2625	2.8
1952–1975	3.8	2625–2650	3.1
1975–2000	1.3	2650–2675	2.5
2000–2025	3.0	2675–2700	1.4
2025–2050	1.4	2700–2725	1.8
2050–2075	2.0	2725–2750	1.3
2075–2100	2.1	2750–2775	2.0
2100–2125	2.0	2775–2800	3.6
2125–2150	2.9	2800–2825	2.4
		2825–2850	2.2
2200–2225	9.2	2850–2875	2.5
2225–2240	8.1	2875–2900	3.2
		2900–2925	2.8
		2925–2944	3.6

The foregoing are based on composite 25-foot samples, or on averages of separate runs, usually of 5 feet. The material at the 225-foot and 325-foot horizons is green spar presumed to be in veinlets. All below 1,600 feet is purple spar in breccia. The highest individual assays were 12.8 percent from 315 to 317 feet and 11 percent from 2,205 to 2,210 feet. Several 5-foot runs exceeded 10 percent slightly, mainly near 1,800 feet. The missing intervals below 1,600 feet represent sections from which satisfactory cuttings were not obtained.

RADIOACTIVITY

Because of the peculiar nature of the breccia encountered in the lower half of this hole, the cuttings were tested for possible radioactivity under the supervision of James W. Hill, a visiting U. S. Geological Survey representative. The tests showed 2 to 4 times normal background count in several sections. Samples from representative sections were submitted later to the Denver laboratory for analysis, under the auspices of the Atomic Energy Commission, results being reported as follows:

Sample	Depth	eU (equivalent Uranium)	U %	Scintillometer count	CaF_2 %
1	1725–1750	.029%	.001	3×	6.4
2	1785–1815	.024	.024	3× – 4×	9.6
3	1975–2000	.001	—	Slight	1.3
4	2150–2175	.016	.001	3×	7.9
5	2370–2400	.011	.001	2× – 3×	10.8
6	2425–2450	.008	.001	2× – 3×	6.6
7	2450–2475	.004	—	2× – 3×	4.6
8	2900–2925	.001	—	Slight	2.8

Mr. Hill, who transmitted the results of analyses for uranium, offers the following comments:

"The amount of radioactivity in four of the samples is significant but the lack of uranium revealed by the chemical analyses indicates that radium, thorium, or some other elements are the cause of the radioactivity."

In view of the uncertainty regarding the matter, additional portions of the cuttings numbered 1 and 2 were submitted to Professor George W. Bain of Amherst College, Amherst, Massachusetts. He reported on these as follows:

RADIOMETRIC

	Initial	On storage	Chemical
1	.0403%	.0389%	.00087%
2	.0439%	.0338%	.00093%

Professor Bain states:

"We are not equipped to assay for thorium but I feel that the departure is not due to thorium. Many daughter elements of uranium migrate more readily than uranium and I suspect something like ionium or some other radium group daughter element as the offender. This would mean that some uranium ought to occur in the vicinity of the diatreme. Sea bottom sediments do accumulate ionium in excess

of the amount in equilibrium with local uranium and then radioactivity is 1,000 times that expectable from the uranium present."

The Denver laboratory, however, in a final report on a detailed spectrographic analysis of the eight samples found .X − % Th in Nos. 1 and 2, .OX + % Th in 4 and 5, trace in 6 and 7, zero in 3 and 8, and concluded that "the moderate radioactivity of the samples is caused largely by thorium and is not of commercial significance at this time."

The Illinois Geological Survey, which has on public file duplicate cuttings from this well, has confirmed the radioactivity of the samples. It may be noted that a 3X count shows at the 228-foot depth in association with the

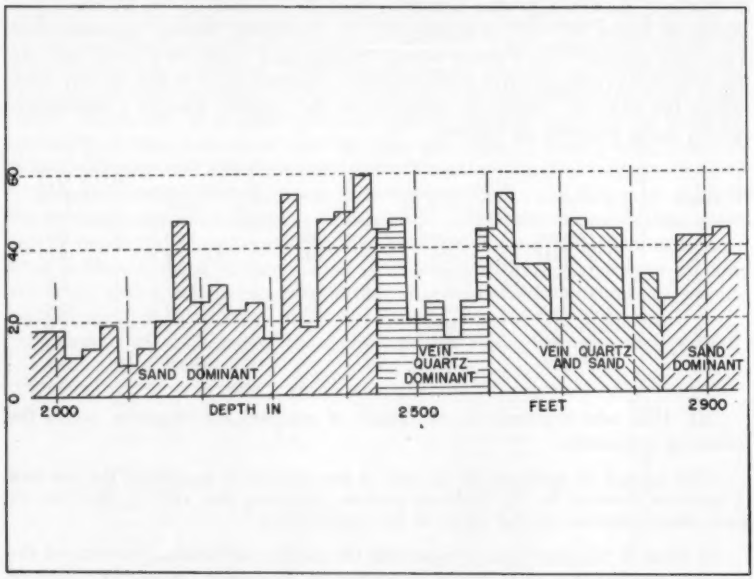


FIG. 3. Histogram of insoluble residues of lower part of Hamp well.

shallow run of fluorspar mineralization, which occurred in cavernous, yellow, and iron-stained rock obviously leached and oxidized by surface waters.

The authors will rest the case for this interesting radioactive anomaly with the observation that the Chattanooga shale (equivalent of New Albany shale horizon in this region) is well known as the carrier of persistent, weak sedimentary concentrations of uranium, and it seems natural to suggest a possible relation between that in the drill hole breccia and the New Albany shale which has barely been removed by erosion from the immediate surface above the hole. Unfortunately, no data as to the radioactivity of the shale in this locality are available. Derivation from the overlying shale would imply surprisingly deep

downward circulation of ground water, or at least mineralizing solution, in the breccia.

On the other hand, the correspondence between the amount of fluorite mineralization and the degree of radioactivity has already been pointed out. It is possible that this is the more significant relation and that there is no connection between the radioactivity and the overlying shale.

PETROGRAPHIC DETAILS

A histogram of the insoluble residues of the brecciated portion of the hole is presented in Figure 3. Sand and vitreous quartz are the predominant constituents, although by volume there is a large proportion of porous honeycombed fragments, evidently networks of fine siliceous replacement of dolomite. These commonly are tinged by purple fluorite replacement. Some chert fragments also are present, and dark shaley matter is fairly common.

One thin section was cut from side-wall core obtained at 321 feet in the upper mineralized zone, the lower Devonian Backbone limestone. This showed considerably brecciated stylolitic limestone cemented by a mixture of fine-

THIN SECTION DATA

HENRY HAMP EXPLOSION BRECCIA

Section	Depth	Summary description
2a	1730	60% dolomite, partly coarse, stylolitic. Several chert fragments (or could be devitrified porphyry?). Three brown altered fragments possibly basic igneous. One piece black shale. Few sand grains. Trace barite and fluorite.
2b	1730	Several limestone fragments with fossils. Several roundish chert grains. Two large pieces black pyritic shale (Maquoketa?). Much purple fluorite replacement and one large barite blade.
3	1747	Heterogeneous dolomite fragments partly replaced by quartz. The vitreous quartz contains considerable pyrite and traces ZnS. Much fluorite present.
4a	1800	Fine-grained mass of milled dolomite and quartz. Considerable angular quartz. One roundish chert fragment. Abundant pyrite or marcasite.
4b	1800	Same with some ragged dolomite grains. Abundant black shale (or bitumen?) showing flowage structures. Much fine iron sulphide and abundant replacement fluorite.
5a	1840	Much sandy dolomite (quartz grains in dolomite cement). Much quartzite, intensely silicified, in large and small grains. Traces fluorite and barite.
5b	1840	Very similar to 5a but the cemented quartzite shows outlines of original sand grains better. One large vitreous quartz fragment with apatite.
6a & b	2205	50% fine-grained dolomite fragments; part is sandy. One good vitreous quartz fragment with included dolomite and apatite. One zircon? fragment. Some fluorite, trace barite.
7	2225	One coarse dolomite fragment banded with 5% fine-grained quartz (sedimentary?). One breccia band of fine dolomite and vitreous quartz. Strong pyritization. Trace fluorite.

grained carbonate and quartz, the latter amounting to about 5 percent by volume of the total. Chalcedonic quartz, some in tiny geodes, and part of it colored by partial rings of limonite, is plentiful, indicating the influence of oxidizing waters, although some unoxidized pyrite is present. There is a little vein calcite. Although brecciated, the fragments are all of one uniform character, unlike the sections described, and the rock is judged to be a normal fracture zone specimen.

The remaining sections studied are from the deeper breccia of presumed explosive origin. Their dominant features are tabulated above.

REFERENCES

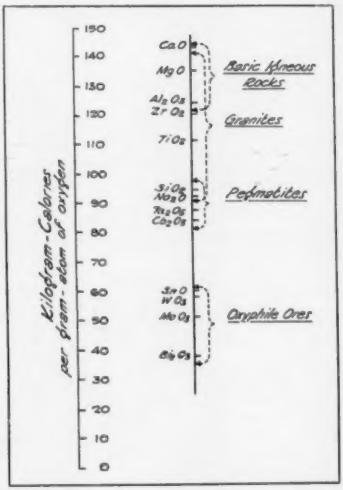
1. Bay, H. X., 1935, and DuBois, E. P., 1944, Log of the Fricker No. 1. Revised by Workman, L. E. and Templeton, J. S., Ill. Geol. Survey, 1950.
2. Weller, S., and St. Clair, S., 1928, Geology of Ste. Genevieve County, Mo.: Mo. Bur. Geol. and Mines, vol. XXII, 2nd ser., p. 93; 97–99.
3. Dake, C. L., 1921, The problem of the St. Peter sandstone: School of Mines & Met., Univ. of Mo., Tech. Ser. vol. VI, Bull 1, p. 9.
4. Bucher, W. H., 1933, Cryptovolcanic structures in the United States: Inter. Geol. Cong. XVI Sess., vol. 2, p. 1055–1084.
5. Weller, J. M., Grogan, R. M., and Tippie, F. E., et al., 1952, Geology of the fluorspar deposits of Illinois: Ill. Geol. Survey Bull. 76.
6. Kidwell, A. L., 1947, Post-Devonian igneous activity in southeastern Mo.: Mo. Geol. Survey Rept. Inv. no. 4.
7. Rust, G. W., 1937, Explosive volcanism in Mo.: Jour. Geol., vol. 45, p. 48–75.
8. Stearns, H. T., 1953, Causes of basaltic explosions: Geol. Soc. Am. Bull., vol. 64, no. 5, p. 599.

St. Joseph Lead Co.,
Bonne Terre, Mo.,
April 12, 1954

DISCUSSION

METALLIC MELTING POINT AND ORE DEPOSITION

Sir: In Table 1 of my paper "Metallic Melting Point and Ore Deposition," ECONOMIC GEOLOGY (vol. 49, Sept.–Oct., p. 555–574), the oxyphile elements were arranged in order of their melting points and the arrangement did not appear to be very significant for geological processes.



Heat of formation of oxides of certain oxyphile elements.
(Data from Rankama and Sahama, 1949.)

In the attached table some key ionic bonding elements are arranged in order of the free energies of formation of their oxides and this arrangement is suggestive of the manner in which the elements are found in rocks and in ore deposits. The data do not suggest the agency of hydrothermal solutions, but suggest a continuous reaction series related to falling temperature.

C. J. SULLIVAN

KENNCO EXPLORATIONS LTD.,
TORONTO, CANADA,
Sept. 27, 1954

COMMENTS ON METALLIC MELTING POINT AND ORE DEPOSITION

Sir: In the article "Metallic Melting Point and Ore Deposition," by C. J. Sullivan (Vol. 49, No. 6, 1954, p. 555), some of the adverse evidence was overlooked in the discussion of certain deposits used as examples. Some of these points should be mentioned at this time.

Lead Deposits, Missouri.—The association of cobalt and nickel in concentrations associated with the low temperature lead ores was not mentioned.

Colorado Plateau Uranium-Vanadium Field.—Mr. Sullivan says on page 568, "The writer considers that a primary concentration of major intensity occurred during the sedimentary cycle, though evidence clearly shows that some reconcentration has occurred." He has neglected the significant contribution of the U. S. Geological Survey (1) who made numerous age determinations of plateau ores by the lead-uranium method. The conclusions in the above mentioned paper are that the uranium was introduced into Triassic and Jurassic sediments not later than late Cretaceous or Early Tertiary.

On page 569 he states, "There is no sign in the comparatively stable Colorado region that extensive granitic activity has taken place, and such activity could not be expected in such a tectonic environment." On the plateau there have been trachytic intrusives emplaced in the vicinity of most known uranium discoveries. To name a few—the Henry Mountains, La Sal Mountains, and Pine Valley Mountain. Many people believe these are related to the ore mineralization.

In his discussion of vanadium (p. 569) he uses the theory he is trying to prove as evidence to support his theory: "The melting point evidence indicates that it is most unlikely that the vanadium has been concentrated by thermal processes."

As a matter of fact, vanadium as descloizite is fairly widespread, though not common, in lead-zinc ores.

Rhodesia-Katanga Copper-Cobalt-Uranium Belt, and Western MacDonnell Range Copper-Nickel Province, Australia.—Certainly most geologists agree that it is possible to have syngenetic ore deposits as well as epigenetic. The author still does not hypothesize the origin of the copper he describes. Was it from erosion of ore deposits of magmatic origin? If so, how does the mention of these two deposits aid in supporting his theory?

On theoretical grounds it is difficult to see how such massive sulfide replacements as those at Cerro de Pasco, Peru, and Jerome, Arizona, could be formed without some transporting agent to remove that which was replaced.

Mr. Sullivan has pointed out some interesting relationships, but in my mind he has proved nothing. The hydrothermal theory, while it may not be valid in all interpretations, has a solid basis of fact to support it, and any attempts to set up new theories should take these facts into consideration.

In usual practice, theory is based on the interpretation of all available evidence, rather that evidence gathered to fit the theory.

RICHARD V. WYMAN

WESTERN GOLD AND URANIUM, INC.,
LEEDS, UTAH,
September 27, 1954

REFERENCE

1. Stieff, L. R., Stern, T. W., and Milkey, R. G., A Preliminary Determination of the Age of Some Uranium Ores of the Colorado Plateaus by the Lead-Uranium Method: U. S. G. S. Circular 271, 1953.

SEDIMENTARY FACIES OF IRON FORMATION

Sir: I have read the valuable paper by Harold L. James in the May issue of ECONOMIC GEOLOGY on the sedimentary facies of iron formation in the Lake Superior region with great interest.

While the suggestion of separate marginal basins on the order of 500 miles in length and 100 miles in width may account for dissimilarities in Lake Superior iron formation stratigraphy, it does not account for the almost entire absence of clastic material in iron formation deposits elsewhere. His final conclusion that the difference between the iron formations of Precambrian age and those of younger age is a difference in degree rather than kind, oversimplifies the problem. Were such an explanation adequate there would not have been such a bibliography as the one given with the paper.

The difference is attributed to the intensity and duration of deep chemical weathering, but no reason is suggested why chemical weathering should have been deeper and more prolonged during a limited Precambrian time than before or since. And what is meant by "deep"?

At Conakry, in French Guinea, at the present time, chemical weathering is forming deposits of lateritic iron ore. The blanket of altered material above the dunite from which it is formed extends locally to depths of over 100 metres, in places extending below sea-level. This laterite contains 50 to 56 percent iron (dry), with nearly a ton of iron per cubic metre. Taking an average thickness of 45 metres the iron content is over 40 million tons per square kilometre. The laterite develops its own protective carapace as a hard surface zone some 7 to 10 metres thick. Below this hard layer the rich iron-bearing material is quite soft, and there may be movement of iron and alumina within the mass.

Are these depths not of the magnitude conceived by James and Woolnough? They are deep enough to give rise to very large iron concentrations, and there seems no reason to suppose that similar deep chemical weathering has not occurred frequently since Precambrian times, but without the formation of the Precambrian type of banded iron formation.

F. G. PERCIVAL

SADLERS END,
HASLEMERE, ENGLAND,
June 29, 1954

Sir: Commenting on remarks made by D. M. Davidson, as printed in ECONOMIC GEOLOGY of June-July, 1954, although not in conflict with his main theme, I disagree with some of his statements and inferences in regard to the Marshall Plan.

The inference is that the mineral procurement effort in Economic Cooperation Administration counted rather heavily in the picture and that this and our overbearing attitude caused much of the present lack of accord between the U. S. and Western European nations that participated in the plan. Actually, the procurement activity was such a small part of the ECA program that it could easily be overlooked in a general survey.

Good training will always improve human capabilities, but in justice to the personnel of ECA, I believe that most of them were well equipped with friendliness, a sincere zeal to make the Marshall Plan work, and genuine eagerness to understand the foreign point of view. As a matter of fact, the Strategic Materials Division of ECA, which I organized and directed for more than a year, found its functions continuously impaired by the tendency of ECA personnel stationed abroad to take on the color of their environment by putting the foregin point of view foremost and by forgetting that the American taxpayers had to work for a living.

In the light of the present tendency of Western Europeans to be critical of the United States, my own conclusion is that first of all, this situation has been brought about by the play of forces that are subsequent and more or less independent. To the extent, however, that any failure of United States foreign policy can be attributed to ECA, it would be, not because ECA personnel were harsh and overbearing, but because they were too soft and too willing to assume that any situation could be cured by mere kindness in the way of smothering all problems with money extracted from United States taxpayers. As I see it, Europe's biggest problem was and is moral, not physical. The European nations that participated in the Marshall Plan and are now most critical of the United States are the ones which lack sufficient moral fiber to rise to their own responsibilities. The nations that had adequate moral fiber benefited from the help, are doing well except for circumstances outside of their control, and are reasonably in accord with our viewpoint. What ECA proved was not a failure of its personnel, but the unalterable fact that neither a man nor a nation can be helped from outside if he or it is not willing to do three-quarters of the job of rehabilitation.

Turning to the contracts made by the ECA Strategic Materials Division, these were made under the most generous terms of a business nature ever conceived up to that time. The United States taxpayers' money was put into enterprises that in private finance would have called for reward in the shape of equity participation, but all we could expect to get back was repayment of the advances in the products of the operations, if they succeeded. Contracts in favor of the United States stockpile over and above amortization shipments were sought only where there was a surplus indicated over European requirements. Some contracts were even more generous. In one case, a group of geologists was furnished at ECA expense to make an extensive survey of Angola and Mozambique. There was no money reim-

bursement to the United States taxpayers; all that was asked was that United States agencies should have access equal to that of Portuguese nationals to the information obtained, and that United States enterprise should have favorable but not preferred treatment in any development that might ensue from this activity. This last consideration really cost nothing as it would be intelligent policy on the part of the Portuguese in any event. They are fully aware that the help of foreign capital in developing their large African holdings would be very beneficial.

EVAN JUST

SCARSDALE, N. Y.
Oct. 12, 1954

SCIENTIFIC COMMUNICATIONS

ARSENIC AND NATIVE COPPER

ROY W. DRIER

An investigation of natural or growth twinning in masses of native copper has revealed some relationships between arsenical copper and arsenic-free copper that may be of interest to geologists. The samples described are small masses of native copper obtained from the stamp mills of Calumet & Hecla, Inc., Calumet, Michigan, and had been broken free from the amygdaloidal lava in which they occur naturally.[1] The writer carried out his investigations in the Metallurgical Engineering Department of the Michigan College of Mining and Technology.

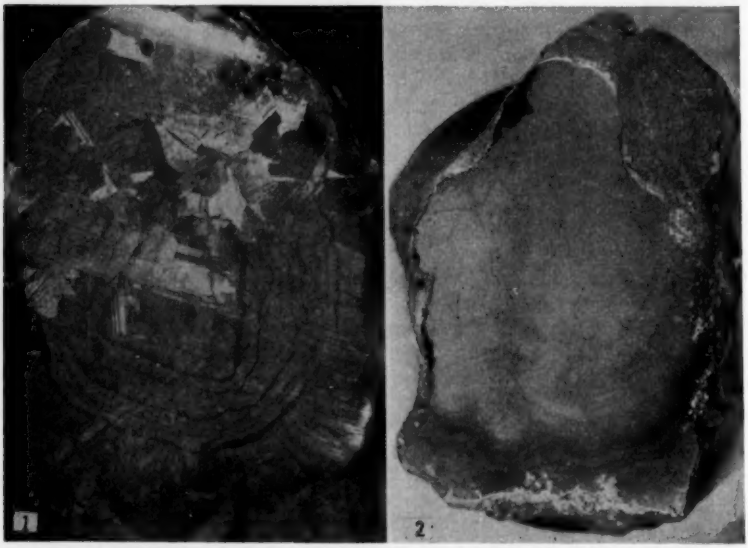


FIG. 1. The dark ring material contains more arsenic than the copper between the rings. × 1.

FIG. 2. Similar to Figure 1. Rings are indicative of changing composition of depositing solutions. × 1.

[1] Butler, B. S., Burbank, W. S., et al., The copper deposits of Michigan: U. S. Geol. Survey, Prof. Paper 144, 238, 1929.

Specimens of mass copper ranging from $\frac{1}{8}$ to 8 inches in diameter were milled smooth on one face in a lathe, and the face so produced was polished on polishing belts and etched with acid ferric chloride. The etchant was made with 25 grams of $FeCl_3$, 25 cc of HCl and 100 cc of H_2O. A light etch, sometimes merely one stroke with a cotton batting swab soaked in the etchant,

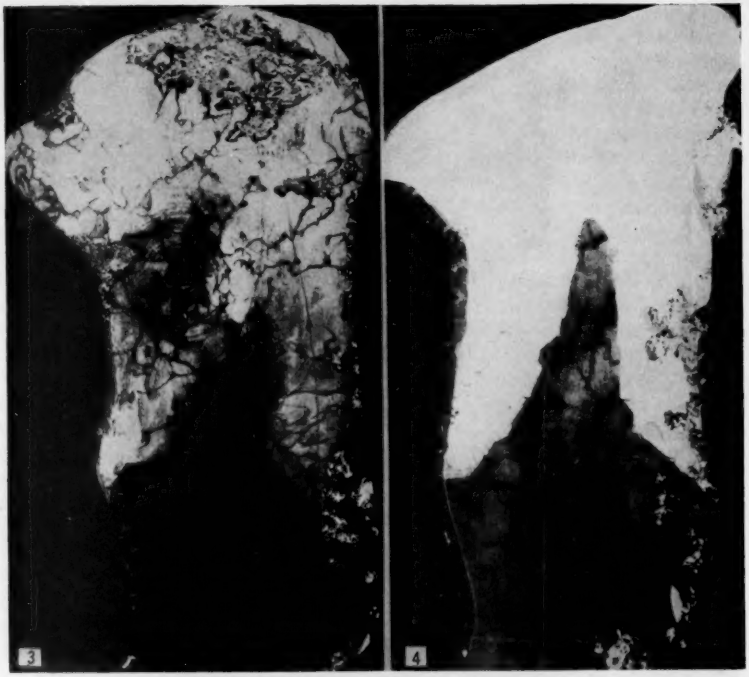


FIG. 3. Illustrates general diffusion of arsenic into copper, immediately adjacent to the dark arsenical phase. It also illustrates the greater diffusibility of arsenic through the grain boundary material of the copper. Upper one-third of the specimen contains 0.0264% As; middle one-third of the specimen contains 0.4620% As; lower one-third of the specimen contains 0.5148% As.

FIG. 4. Illustrates differential arsenic content within the arsenical phase itself. × 1.

was sufficient to show up the arsenic-bearing phase. To show up the granular structure of the metal an extended etch, or even a strong etchant like nitric acid, was needed. The arsenic-bearing phase turned dark on etching with the acid ferric chloride. When the etched face is not polished, and so has more surface area per square inch than a polished face, the arsenical phase appears much darker. Figure 4 was polished, figure 3 was not, so the arsenical phase

in Figure 3 appears much darker. Some differences in darkness are apparent even within the arsenical phase of Figures 4 and 5.

Spectroscopic analysis of the darker colored copper shows that it is much higher in arsenic than the lighter colored copper, and the relative darkness, furthermore, appears to be proportional to the arsenic content. The arsenic content of the copper in the specimens studied ranges from about 0.002 to

FIG. 5. Illustrating general diffusion of arsenic into copper. Dark areas are arsenical. Higher arsenic content is indicated by greater intensity of darkness. × 1.

FIG. 6. Illustrating intergranular diffusion. Specimen contains 0.019% As. × 1.

0.515 percent. When a group of etched samples is arranged in order of increasing amounts of the darker arsenical copper, it is possible to use this series as a scale for fairly accurate visual estimations of the arsenic content in specimens of unknown content. Arsenic percentages of the specimens illustrated in Figures 3 and 6 are given in the captions. The individual mine from which

a given specimen of recently mined mass copper came can also be fairly reliably guessed from the amount and appearance of the arsenical copper as brought out by this technique.

Two types of relationship between arsenical and arsenic-free copper have been observed. The first and least common phenomenon is an alteration of bands of more and less arsenical copper that closely resembles the concentric Liesegang ring formation of agates and similar crystal growths. (See Figs. 1 and 2.) Possibly 2 or 3 percent of the specimens studied show this structure. The concentric rings represent an onion-structure in three dimensions, as was shown by cutting, polishing, and etching one specimen on two faces at right angles to one another. These shells of more arsenical copper cross individual grains and few of the irregularities in the shells seem to be related in any way to grain boundaries or grain orientation. Except near the center of the specimen of Figure 1, irregularities that are convex toward the centers of the specimens seem to be more acute, in general, than the irregularities that are concave toward the centers, which suggests that the masses have grown by accretion about a central nucleus rather than in from the walls of a cavity. If this interpretation is correct, the solutions that deposited the mass of Figure 2 became progressively more arsenical with time, whereas those that deposited the mass of Figure 1 show no well-defined trend. Both specimens suggest a rather rhythmic fluctuation in the arsenic content of the depositing solutions.

A second and more common phenomenon is illustrated in Figures 3 and 4. In these the more darkly stained arsenical copper seems to have the relationship of an invader in the arsenic-free copper. The intimate penetration along grain boundaries, working out from the completely blackened body of very arsenical copper in the lower part of Figure 3, suggests that arsenic has in some way been introduced into the mass after its original formation.The larger tongue-like penetration of arsenical copper, more striking in Figure 4 than in Figure 3, suggests the same phenomenon. The specimen of Figure 4, more highly polished, more lightly etched and with less photographic exposure than Figure 3, shows what appear to be incompletely altered islands of slightly less arsenical copper even within the high-arsenic area. Figure 6 suggests arsenic diffusing intergranularly into the copper.

These preliminary results show the existence of mixtures of arsenical and non-arsenical copper that have not been hitherto recognized, and suggest a technique for further investigation of the geologic controls of arsenic distribution in the mines of the Michigan copper district.[2]

DEPT. OF METALLURGICAL ENGINEERING,
MICHIGAN COLLEGE OF MINING AND TECHNOLOGY,
HOUGHTON, MICHIGAN,
July 27, 1954

[2] Broderick, T. M., Zoning in Michigan copper deposits and its significance: ECON. GEOL., vol. 24, p. 149–62, 311–24, 1929.

REVIEWS

Minerals for Atomic Energy. By ROBERT D. NININGER. Pp. 367; figs., colored plates, charts. D. van Nostrand Co., New York, 1954. Price, $7.50.

This opportune book comes at a time when the search for atomic minerals is growing apace. Its title states that it is "A guide to exploration for uranium, thorium, and beryllium," and is meant to be a complete handbook for prospecting for these minerals. The author is Deputy Assistant Director for Exploration, Division of Raw Materials, U. S. Atomic Energy Commission, and is therefore uniquely qualified to write about the subject. The book is organized to assist the untrained, the prospector, and the professional geologist. It presents an understanding of what and where to look, the tools and methods to use, and how to evaluate a find.

Part I, What to Look For, gives information about the minerals and mineral deposits that are actual or potential sources of radioactive minerals. It gives the mineralogy, geology and identifying marks of possible deposits. Part II is a survey of world areas that are favorable for the occurrence of atomic energy minerals. Part III deals with prospecting equipment, techniques, evaluation, prices, markets and government controls. Sixteen appendices cover minerals, mineral identification, classification of mineral deposits, sampling and testing, government information sources, manufacturers and distributors of equipment, laws and regulations, staking mining claims, prices and markets, and information on occurrence in British Commonwealth and other countries, including Russia.

The book is the very best that has appeared on this general subject. It brings together a wealth of information regarding radio-active minerals and should prove invaluable for the prospector and a handy reference book for the geologist. One must mention the five fine color plates of various atomic energy minerals.

Petroleum Microbiology. By ERNEST BEERSTECHER, JR. Pp. 375; figs. 71. Elsevier Press, Houston, Texas, 1954. Price, $8.00.

This rather unusual book is stated to be "An Introduction to Microbiological Petroleum Engineering"—a bringing together of two fields of work. In it the author points out the possibility of oil discovery through the presence of a particular bacterial flora in the soil, the role of bacterial ferments in drilling mud, problems relating to cause and prevention of plugging up of oil formations by multiplication of bacteria, the use of bacterial catalysts in the fabrication of petroleum products, and many other interesting phenomena in the relation of bacteria to petroleum. The contents are largely oriented from the standpoint of petroleum engineering.

The book is divided into three main parts, following an introduction—Exploration, Production, and Manufacturing. Under the first is considered the "Role of Microorganisms in Geological Processes,"—the role in the "Synthesis of Petroleum," the "Microbial Utilization of Petroleum Hydrocarbons," and the "Use of Microorganisms in Petroleum Explorations." Under Production are chapters on the activities of microorganisms in drilling muds, in petroliferous formations, and in corrosion. Under Manufacturing are three chapters on "The Effects of Hydro-

carbons upon Microorganisms," "Use of Microorganisms as Reagents in the Manufacture of Petroleum Products" and "Petroleum and its Products as Sources of Infectious Microorganisms." These are followed by a glossary and index. References are given at the end of each chapter.

Petroleum technology and microbiology and biochemistry are intimately blended with good effect. The author, an associate professor of Biochemistry at the University of Texas, is an authority on Microbiology and Biochemistry, and has a knack of presenting scientific information directed to practical application. It is a book that should interest petroleum geologists and petroleum engineers.

Structural Geology. By MARLAND P. BILLINGS. 2nd edition, 1954. Pp. 514; figs. 381. Prentice-Hall Inc., New York. Price, $6.95.

This new edition, after a lapse of 12 years, follows the general policy of the earlier edition with emphasis on the principles of structural geology. Of course the text matter has been brought up to date, three new problem exercises have been added and some of the other exercises have been modified.

The 23 chapters, as before, cover mechanical principles, folds and folding, rupture, joints, faults with their classification recognition and mechanics; causes of folding and faulting, unconformities, salt domes, extrusive and intrusive igneous rocks and bodies, cleavage and schistosity, lineation, structural petrology, and geophysical methods in structural geology, followed by 13 laboratory exercises.

Like its predecessor this edition should become the leading text book and reference in structural geology.

Minerals, for the Chemical and Allied Industries. By SIDNEY J. JOHNSTONE. Pp. 692. John Wiley & Sons, New York, 1954. Price, $11.50.

This book by the former Principal of the Mineral Resources Department of the Imperial Institute, London, is pointed to make information about the qualifications of minerals available to mineral producers. It serves also to give knowledge of the properties, specifications, and uses of minerals to consumers of minerals, particularly those of the chemical industries.

Seventy-one minerals and mineral groups are considered. For each there is given the natural minerals, sources, metallurgy or beneficiation, specifications, production, uses, consumption, and bibliography. The book thus gives concentrated information regarding most of the metals and minerals used in industry and should prove to be a handy general reference book for all of those interested in the mineral industry.

A Historical Survey of Petrology. By F. J. LOEWINSON-LESSING, translated by S. I. TOMKEIEFF. Pp. 112. Oliver and Boyd, Edinburgh, London, 1954. Price, 12/6.

This book was published by Professor Loewinson-Lessing in Russian in 1936, as a survey of the trends of petrology during the preceding half-century, with his own personal views interwoven. The translation into English was completed by Dr. Tomkeieff in 1939, but publication was delayed owing to the outbreak of war. The translator states he resisted the temptation to bring the book up to date because it is a record of the petrological experience of the author. He did, however, add some material drawn from the author's latest publications, and added to the 18-page bibliography some fifty titles of later publications.

The author, after an Introduction, divided his work into five titles, the Geological, Petrographical, Chemical, Experimental, and Synthetic approaches, covering under each the history of developments up to the date of writing (1936). Interspersed are his own comments.

The book is an interesting history of the development of petrology from the premicroscopic to the microscopic eras, viewed through the eyes and thoughts of an eminent petrologist. It is stated to be "the first book dealing with the history of petrology as such to be published in the English language. All petrologists will wish to read it.

Geographical Essays. By W. M. DAVIS, 1909. Republished unabridged, 1954. Pp. 777; figs. 130. Dover Publications, New York. Price, $5.50.

This great classic by the most renowned physiographer and geographer has long been the leader and guide to all later geomorphologists and geographers. Its republication will permit those who have been unable to possess a copy of their own now to have one in their own library for reference and instructive reading. Davis' notable drawings can now be more widely appreciated. Since most geologists and geographers have either known or been brought up on this book, the listing of its contents is unnecessary.

BOOKS RECEIVED

KURT SERVOS

U. S. Geological Survey, Washington, D. C., 1954

Prof. Paper 254-C. Nonmarine Mollusks from Barstow Formation of Southern California. D. W. TAYLOR. Pp. 67–80; pls. 20. Price, 30¢. *This formerly unknown Cenozoic nonmarine mollusk fauna from the southern Great Basin includes four new species.*

Prof. Paper 254-D. Two new Plant Genera of Pennsylvanian Age from Kansas Coal Balls. S. H. MAMAY. Pp. 81–95; figs. 2–4; pls. 21–23. Price, 55¢. *Descriptions of a new sporangium and a new pteridospermous seed.*

Prof. Paper 254-F. Distribution of Some Shallow-Water Foraminifera in the Gulf of Mexico. O. L. BANDY. Pp. 125–140; figs. 5–13; pls. 27–31. Price, $1.00. *Detailed study of the ecology and distribution of Foraminifera and of the median grain size of the sediments.*

Prof. Paper 254-H. Triassic Stratigraphy of Southeastern Idaho and Adjacent Areas. BERNHARD KUMMEL. Pp. 165–194; figs. 18–21; pls. 34–40. Price, $1.00. *The strata of Lower Triassic age include rocks of both miogeosynclinal and continental origin. The Dinwoody formation contains previously unknown ammonite faunas. Many geologic sections and correlation diagrams.*

Prof. Paper 254-I. Carolina Bays and the Shapes of Eddies. C. W. COOKE. Pp. 195–207; figs. 22–25; pls. 41–53. Price, 70¢. *Interpretation of the most symmetrical of the Carolina bays as the sites of former tidal eddies.*

Prof. Paper 257-A. Lake Bonneville: Geology of Northern Utah Valley, Utah. C. B. HUNT, H. D. VARNES and H. E. THOMAS. Pp. v, 99; figs. 22; pls.

4; tbls. 28. Price, $2.25. *Some sediments are useful as foundation materials and as processed or unprocessed construction materials. The principal sources of groundwater are the pre-Lake Bonneville Pleistocene deposits and the older Cenozoic (?) deposits. The major portion of the Paper is an account of the general geology. Geologic map, 1:62,500; engineering geologic map, groundwater map, 1:62,500; six geologic sections based on well logs.*

Prof. Paper 264-A. Ostracoda from the Permian of the Glass Mountains, Texas. I. G. SOHN. Pp. 1–24; figs. 2; pls. 5. Price, 75¢. *Thirteen of 18 species of ostracodes are new and one is unnamed.*

Circ. 230—Airborne Radioactivity Surveys for Phosphate in Florida. R. M. MOXHAM. Pp. 4; fig. 1; pls. 8. *Locations of anomalies found by airborne traverses.*

Circ. 334—Uranium-Bearing Copper Deposits in the Coyote District, Mora County, New Mexico. H. D. ZELLER and E. H. BALTZ, JR. Pp. ii, 11; figs. 3; pl. 1. *Chalcocite (with some bornite, covellite, pyrite, and malachite) averages 3% Cu and the U amounts to as much as 0.067%. The deposits are syngenetic in the Sangre de Cristo formation.*

Circ. 335—Reconnaissance for Radioactive Deposits in East-Central Alaska, 1949. HELMUTH WEDOW, JR., M. G. WHITE AND OTHERS. Pp. iii, 22; figs. 6; tbls. 11; pls. 2. *Record of brief radioactivity reconnaissance investigations. In the Eagle district radioactivity is associated with Cu mineralization in metasediments.*

U. S. Atomic Energy Commission, Tech. Inform. Service, Oak Ridge, Tenn., 1954

RME-3093 (Pt. 1). Relation of Sedimentary Trends, Tectonic Features, and Ore Deposits in the Blanding District, San Juan County, Utah. W. L. STOKES. Pp. 33; figs. 7. *Structural control of stream flow in Jurassic time seems to have localized later uranium-vanadium mineralization in Salt Wash sandstone.*

RME-3093 (Pt. 2). Sedimentary Features and Mineralization of the Salt Wash Sandstone at Cove Mesa, Carrizo Mountains, Apache County, Arizona. D. J. JONES. Pp. 40; figs. 23. *There is cyclic repetition of sedimentary units in Salt Wash sandstone. The pattern of the sandstone-shale ratio maxima correlates with the directional pattern of stream flow.*

California Division of Mines. Mineral Information Service, Vol. 7, No. 8. Dept. of Natural Resources, San Francisco 11, 1954

Pub. in Geol. Sciences, Vol. 29, No. 9. Mode of Origin of Pyroclastic Debris in the Mehrten Formation of the Sierra Nevada. G. H. CURTIS. Pp. 453–502; figs. 4; pls. 35–45. Univ. of Cal. Press, Berkeley & Los Angeles, 1954. Price, 75¢. *The andesitic volcanic debris of Upper Miocene (?) and Lower Pliocene age once covered an area probably exceeding 12,000 square miles. Origin is by autobrecciation of slowly moving lava.*

Pub. in Geol. Sciences, Vol. 30, No. 2. Foraminifera from the Gaviota Formation East of Gaviota Creek, California. E. J. WILSON. Pp. 103–170; figs. 3; pls. 12–18. Univ. of Cal. Press, 1954. Price, $1.00. *The Gaviota formation of Oligocene (Refugian) age contains 62 species and varieties of Foraminifera and 13 species of marine megafossils. Eponides gaviotaensis is a new species. Wilson describes ecology and correlation of the formation.*

Illinois State Geol. Survey. Urbana, Ill.

Petroleum No. 70, Developments in Illinois and Indiana in 1953. A. H. BELL and T. A. DAWSON. Pp. 1078–1090; fig. 1; tbls. 11. *In 1953, 3473 wells were drilled for oil and gas in Illinois and Indiana; total production was more than 71.6 million barrels. Most of the new producing zones are in middle Paleozoic, some in lower Paleozoic, rocks.*

Kansas State Geological Survey Bull. 107

Oil and Gas Developments in Kansas During 1953. W. A. VER WIEBE AND OTHERS. Pp. 204; figs. 16; tbls. 57; pls. 2. Univ. of Kansas, Lawrence, 1954. *Kansas oil production in 1953 totaled almost 114.4 million barrels, gas production was 420.6 billion cu. ft. Proved reserves of crude oil are 913 million barrels.*

Minnesota Geological Survey, Minneapolis, Minn.

The Stratigraphy and Structure of the Mesabi Range, Minnesota, 1954. D. A. WHITE. Pp. xiv, 92; figs. 19; tbls. 11; pls. 4. University of Minnesota, Minneapolis, Minn. Price, $2.50. *The Upper Precambrian Animikie group includes the Pokegama (quartzite), Biwabik (iron-bearing), and Virginia (argillite) formations. There is evidence of both penecontemporaneous and diagenetic origins for the chert and iron minerals. Eleven structure contour maps, 1: 31,250; geologic map, 1: 62,500.*

Missouri Div. of Geol. Sur. and Water Resources

Rept. of Investigation 15. Rolla, 1954. The Geology of the Humansville Quadrangle, Missouri. T. K. SEARIGHT. Pp. 50; pls. 3. *The formations range from Ordovician to Pennsylvanian in age. Geologic map, 1: 24,000.*

Rept. Investigation 16. The Structure and Magnetic Surveys of the Sullivan-Bourbon Area, Missouri. T. K. SEARIGHT AND OTHERS. Pp. iii, 14; pls. 4; tbl. 1. *Investigations of magnetic anomalies have disclosed mineralization of both hematite and magnetite.*

New York State Science Serv. Albany, 1954

Rept. of Investigation No. 5. Magnetic Anomalies of the Paradox Lake, N. Y., Quadrangle. B. M. SHAUB. Pp. ii, 13; fig. 1; tbls. 2; pls. 11. *Accessibility, geology, description, statistics, and potentiality of each dip-needle anomaly.*

North Dakota Geol. Sur. Circ. Nos. 78–86

Each circular contains lithologic description of rocks encountered in drilling the following wells: Elmer Tank No. 1 Well, Frank A. Fischer No. 1, John Gangl et al. "A" No. 1, Well No. 434, H. Amann No. 1, Ohlhauser No. 1, Wendell Haley No. 1, O. Gunderson No. 1, Chris Linnertz No. 1.

Ohio Dept. of Natural Resources, Columbus, Ohio, Div. of Water Bull. 28, 1954

Ground Water Levels in Ohio, 1951–52. PAUL KASER. Pp. x, 95; figs. 132; tbls. 3. *Inventory of hydrologic conditions including summary of basic geologic concepts.*

List of the Principal Operators and Owners of Mines and Quarries in the Province of Quebec. 1953. Pp. 90.

Province of Ontario Metal Resources Circular No. 1. 3rd Ed. 1954

Copper, Nickel, Lead, and Zinc Deposits in Ontario. J. E. THOMSON AND OTHERS. Pp. i, 68. *Inventory report of some mineral properties in Ontario.*

Each description includes ownership, location, metals, development, geology, reserves.

Canadian Department of Mines

The Mining Industry of the Province of Quebec in 1952. Pp. 114; figs. 2; pls. 8. *General review, mining operations, development, and statistical data.*

Geol. Report 60. Maicasagi Area Abitibi-East County. P. E. IMBAULT. Pp. 34. *Description of areal geology. Slight mineralization is widely dispersed: gold, silver, and copper are negligible; pyrite is common; chalcopyrite is less abundant. Geologic map, 1:63,360.*

Australian Bur. of Mineral Resources, Geology and Geophysics, Melbourne. Quarterly Rev. Vol. 6, No. 4. May, 1954.

The Australian Mineral Industry. J. A. DUNN. Pp. iii, 113–150. Price, 3/–. *Statistics of economic mineral production.*

British Territories in Borneo

Annual Report of the Geological Survey Dept. for 1953. F. W. Row. Govt. Printing Office, Kuching, Sarawak. 1954. Pp. v, 127; figs. 9; pls. 21; tbls. 13. Price, M$ 3.00 or 7/–. *Sediments range from Permian to recent in age; the tectonic history is complex. Economic production during 1953 included more than 36.8 million barrels oil, 442 fine ounces gold, and 632 long tons phosphate.*

The Inst. of Min. and Metallurgy. London E. C. 2

Abstracts, Vol. 4, No. 6. Pp. 283–331. Price, 5/–. *Annotated survey of world literature on economic geology, mining, metallurgy, and related subjects.*

Radioactivity and Chemistry of Some Indonesian Eruptive Rocks. J. WESTERVELD. North-Holland Publ. Co., Amsterdam. 1954. Pp. 52, figs. 13; tbls. 11. Price, *f* 4.50. *Indonesian igneous rocks show a relation between total radioactivity intensity, β-emission intensity, and Ra content and that of SiO_2 and K_2O weight percentages. Tin granites may be a future source of fissionable materials.*

Mem. of the Rajputana University, Dept. of Geology, India. Udaipur. 1953

No. 1. A New Theory of Sheet Movements and Continental Expansion. K. P. RODE. Pp. 30; figs. 10. *Suggestions of a working hypothesis to solve geological enigmas.*

No. 2. The Gondwana Formations of India and the Nature of Gondwanaland. K. P. RODE. Pp. 12; figs. 5; tbls. 2. *The Gondwana formations include the main coal deposits. Gondwana formations of other continents are supposed to have been derived by sheet movement and consequent continental expansion.*

Geological Survey of Japan—Hisamoto-cho, Kawasaki-shi, Japan, 1953–54

Explanatory Text of the Geological Map of Japan. Wakimachi—Zone 30, col. 16. Sheet 231. KEN HIRAYAMA. Pp. 34, 11. *Areal geology is detailed; ore reserves of 770,000 tons (in 1949) average 1% Cu content. In Japanese. Geologic map, 1:75,000.*

Oyaichiba (Okayama-34). OSAMU HIROKAWA, HUMIO TOGO and NOBUKAZU KAMBE. Pp. 31, 10; tbl. 1. *A spectrum of igneous rocks composes the region. Numerous copper-tin veins are composed of chalcopyrite, bornite, cassiterite, wolframite, spalerite, and gelena; with scheelite, bismuth, bismuthinite, siderite and pyrrhotite. In Japanese, English summary. Geologic map, 1:50,000.*

Tajima-Takeda (Okayama-35). OSAMU HIROKAWA, HUMIO TOGO and NOBUKAZU KAMBE. Pp. 20, 9; tbl. 1. *The ore of micaceous iron deposits contains*

36% Fe; some fissure fillings in rhyolite lava have 0.32% Cu, 0.37% Pb, and 1.56% Zn; quartz-fluorite veins carry from 40 to 70% CaF_2. In Japanese, English summary. Geologic map, 1: 50,000.

Bulletin Mexico, D. F., Tomo III, No. 7, July, 1954. Pp. 1231–1408. Price, 75 pesos (12 numbers). *Bibliography of sciences in Western Hemisphere.*

Annual Report of the Geological Survey of Sierra Leone for the Year 1952. Freetown. Pp. 22. Price, 1/6. *Includes reports of geological investigations.*

Southern Rhodesia Geological Survey Bull. No. 40

The Geology of the Lower Sabi Coalfield. W. H. SWIFT AND OTHERS. Salisbury, 1953. Pp. 96; pls. 17; tbls. 6. Price, 15/–. *Coal belongs to the Lower Karroo (Beaufort) System. Description of other economic mineral deposits.*

SCIENTIFIC NOTES AND NEWS

RICHARD N. HUNT, vice president and chief geologist of the United States Smelting, Refining and Mining Company, Salt Lake City, Utah, has been named to the board of Hecla Mining Company, Wallace, Idaho.

W. HUBER, geologist for the Eastern Mining and Metals Co., Ltd., Singapore, is on his way to Switzerland from Malaya where he has been studying iron ore operations for the company. Dr. Huber has been visiting the United States on his way to Europe and has toured several iron ore mines on the Mesabi Range.

J. V. HARRISON, professor of geology at the University of Oxford, is now on his fifth geological expedition to Peru. Included in his current program are geological exploration of the Andes between Huancayo and Chincha and between Morococha and Oroya, revision of the geological survey work carried out last year between Junin and Pasco, and continuation of a geological survey of the Central Andes. His work is in cooperation with the Peruvian Institute of Geology and other organizations.

THOR H. KIILSGARD, geologist at the USGS Spokane office, has been promoted to staff assistant to the chief of the agency's mineral deposits branch at Washington, D. C.

NORMAN H. FISHER, Australian geologist, has been in Bolivia, assisting the Bolivian Mining Corp. in a survey of that nation's mineral resources.

K. W. F. ITEN, former geologist-in-charge, Cerro de Pasco geological department, is now in the Philippines with Benguet Consolidated Mining Co., Balatoc.

LLOYD M. SCOFIELD, mining geologist and mining engineer, has opened a consulting office at 1014 Fidelity Bldg., Duluth.

HENRY L. HOSMER, formerly geologist, Morococha Div., is now assistant chief geologist of mines for Cerro de Pasco in La Oroya, Peru. Mr. Hosmer recently returned to Peru after a long vacation during which he did graduate work at the University of Michigan.

JAMES E. ATKINSON, San Francisco mining engineer and geologist, has been engaged as consultant for the new columbite-tantalite project of the Morabisi Mining Co. Ltd., P. O. Box 183, Georgetown, British Guiana.

CHARLES H. BURGESS, who was district geologist, Kennecott Copper Co., New York, is now with Bear Creek Mining Co., Minneapolis.

L. S. BRECKON, who spent two years as district geologist for Kennecott Copper Corp. in Australia and the Far East, is now chief of the Land Division for Bear Creek Mining Co. Mr. Breckon will make his home and headquarters in Salt Lake City.

J. FRANK SHARP, former underground surveyor and later chief geologist at Consolidated Coppermines Corp., Kimberly, Nev., has taken over his new duties as superintendent of operations there.

JULIAN W. FEISS, staff geologist for Bear Creek Mining Corporations, exploration subsidiary of Kennecott Copper Corp., recently made a tour of the firm's western field offices.

THOR H. KIILSGAARD, project chief for DMEA activities of the U. S. Geological Survey in Region II with headquarters in Spokane, Washington, has been promoted to staff assistant to the chief of mineral deposits of the USGS in Washington, D. C.

KENNETH L. COOK, associate professor and head of the department of geophysics, University of Utah, was recently appointed to the Executive Committee of the Mining, Geology and Geophysics division of the American Institute of Mining and Metallurgical Engineers.

HANS P. RECHENBERG, geologist for the Bolivian Mining Company in La Paz, Bolivia, has accepted an appointment as assistant professor of Mining Geology at the Technical University in Berlin, Germany.

EDWARD FITZHUGH, chief geologist of the Republic Steel Corp., has been in Lima, Peru, inspecting drill operations at the Acari iron ore deposits.

CHARLES F. PARK, JR., dean of the Stanford University School of Mineral Sciences, spent part of the summer investigating Mexican iron deposits for the Bethlehem Steel Company.

HERBERT KURSELL, former head of explorational operations for the American Smelting and Refining Company, is acting as general consultant for the Marcona Mining Company, W. R. Grace and Co., and the Cerro de Pasco Corporation in Lima, Peru.

A. F. MATHESON has returned to Noranda, Que., from Brazil, where, for the past three and a half years he has been geologist for the St. John Del Rey Mining Co., at Nova Lima, Minas Geraes.

D. R. DERRY, formerly chief geologist for Ventures Limited, has relinquished this position to join Rio Canadian Exploration Limited, Canadian subsidiary of the British Company, Rio Tinto Mines Limited, as executive vice-president.

W. P. HEWITT, geologist, American Smelting & Refining Co., who was with the Mexican Div., El Paso, Texas, is now with the western mining dept., Salt Lake City.

J. BRIAN EBY of Houston, former chief of the Shell Oil Co.'s Gulf Coast geophysical department and an independent consulting geologist for many years, has been named a director of Texas International Sulphur Co.

W. B. MATHER, chairman of the mineral technology department, Southwest Research Institute of San Antonio, has returned to the U. S. after spending four months studying phosphate deposits in Brazil.

CARL TOLMAN has been named vice chancellor and dean of faculties at Washington University, in which capacity he has been acting since June, 1953. Since 1946 he has held the position of dean of the Graduate School of Arts and Sciences and for the past nine years he has also been professor of geology and geological engineering and chairman of the department.

P. T. FLAWN has taken three months leave-of-absence from The University of Texas, Bureau of Economic Geology, to act as consulting geologist with the Surface Geological Company in Albuquerque, New Mexico.

The U. S. Geological Survey has recently reorganized its Geochemical Prospecting Section into a Geochemical Exploration Section. The new Section is under the direction of T. S. LOVERING and is headquartered at the Federal Center, Denver, Colorado. The GX Section, as it is called, is concerned mainly with research on the fundamental principles that underlie the distribution, migration,

and concentration of elements in the earth's crust, especially in the vicinity of mineral deposits; as well as on chemical methods for the determination of these elements in soil, rock, water, and plants. The actual application of these geochemical techniques to the study of mining districts and other problems will be carried out chiefly by Survey geologists outside the Section, but the GX Section will provide consultants, samplers, and will make the trace analyses.

RUSSELL GIBSON has returned to Iran after a vacation in the United States. Since his retirement from Harvard University he has been in the employ of the U. S. Government, with headquarters in Teheran.

The ASSOCIATION OF MISSOURI GEOLOGISTS was organized at a meeting held at the office of the Geology Department of the St. Joseph Lead Company, Bonne Terre, Missouri, October 10–11.

The Association has 103 charter members of whom 61 were present at the Bonne Terre meeting. The following are the first officers of the new organization:

President: Dr. O. R. Grawe, Chairman, Geology Department, School of Mines and Metallurgy, University of Missouri, Rolla; Vice-President: Dr. Norman S. Hinchey, Vice-Chairman, Department of Geology and Geological Engineering, Washington University, St. Louis; Secretary-Treasurer: Dr. Walter V. Searight, Principal Geologist, Missouri Division of Geological Survey and Water Resources, Rolla; Members of Executive Committee: Dr. Frank Snyder, Geologist, St. Joseph Lead Company, Leadwood; Dr. Athel G. Unklesby, Associate Professor, Geology Department, University of Missouri, Columbia.

JAMES BOYD, exploration manager of Kennecot Copper Corp., Denver, and former director of the U. S. Bureau of Mines, addressed the eighth annual Midwestern meeting of the Society of Exploration Geophysicists November 18 in Dallas.

DAVID C. SHARPSTONE, consulting geologist to the Ventures Group, and chairman and managing director of Kilembe Mines Limited, has been appointed a director of the Uganda Development Corporation through an order in council by His Excellency Sir Andrew Cohen, Governor of Uganda.

H. WILLIAM AHRENHOLZ, JR., associate professor of mining engineering, West Virginia University, Morgantown, has become reaffiliated with The New Jersey Zinc Co., and is in charge of the Ivanhoe mine now under development. His address is Bertha Mineral Div., The New Jersey Zinc Co., Austinville, Va.

WILLIAM A. BOWES, geologist, who was with Shenon & Full, Consultants, Salt Lake City, is now with the Atomic Energy Commission, Salt Lake Exploration Branch, Div. of Raw Material, Salt Lake City.

The DALLAS COUNCIL ON WORLD AFFAIRS held a Mineral Resources Conference in Dallas on Nov. 15, 16 and 17. Salker L. Cisler, President of the Detroit Edison Company, spoke on "Energy Sources for the Future." Cisler's address will be the concluding event according to H. N. Mallon, President of the Council. Dr. Arthur S. Flemming, Director of the Office of Defense Mobilization, spoke on "Mineral Resources, Stockpiling and American Security." Other participants were F. S. Bryant, Vice President and Director of the Standard Oil Company of California; Julian Tobey, President of Appalachian Coals, Inc.; James Boyd, Exploration Manager of Kennecott Copper Corporation; and Rex G. Baker, Vice President and Counsel of Humble Oil and Refining Company. Subjects scheduled for discussion are Minerals in World Trade, Mineral Requirements of an Expanding Economy, Known U. S. Resources, and Closing the Gap, through increased exploration, beneficiation, conservation and substitution.

ROGER C. BAKER, formerly district geologist of the U. S. Geological Survey at Little Rock, Ark., has gone on a two-year assignment to assist the Pakistan government in developing a program of ground-water investigation. He will also aid in the collection and study of basic geologic and hydrologic information necessary for the development of vital resources for that country. Mr. Baker has been in charge of the ground-water program in Arkansas since 1946, except from March to October 1952, when he was on assignment to Libya with a similar assistance program of water-resources investigation.

PHILIP E. LAMOREAUX, district geologist of the U. S. Geological Survey at Tuscaloosa, Ala., left Washington recently on a three-month assignment to assist the Thailand government in planning a program of ground-water investigation, and will initiate studies directed toward the collection of basic geologic and hydrologic information necessary for the development of vital water resources for the country. In 1953 he was on assignment to Egypt making a similar water-resources study.

DR. JAMES D. FORRESTER, director of the Idaho Bureau of Mines and Geology and Dean of the College of Mines, announces the following staff changes: Lewis S. Prater has been promoted to assistant director of the bureau in addition to his duties as bureau metallurgist. Harold A. Powers, formerly employed by the National Lead Company, was named bureau geologist. Charles R. Kurtak was appointed chemist-analyst for the bureau to take over somewhat expanded duties. An additional appointment for a mining engineer in the bureau will be made shortly after January 1. The staff additions will provide full-time engineers and scientists working in the areas of geology, mining and metallurgy, supported by the chemical and mineral identification service. Research fellows and part-time summer employes will also be utilized to augment the bureau program of increased service to the state in mineral-resource development.

The SOCIÉTÉ GÉOLOGIQUE DE BELGIQUE is celebrating the 75th birthday of Paul Fourmarier, honorary Secretary General and former President of the Society. The occasion will take place November 28, 1954, at the University of Liege. In commemoration, the society will produce a volume in his honor on the geology of Belgium. There were individuals representing many universities and scientific organizations.

K. A. DAVIES, formerly Director of the Geological Survey of Uganda, has succeeded R. W. WILLETT as British Commonwealth Geological Liaison officer. Dr. Willett has returned to the New Zealand Geological Survey at the close of his term of office in London. Dr. Davies's address is: British Commonwealth Geological Liaison Office, Africa House, Kingsway, London, W.C. 2.

INDEX TO VOLUME XLIX

[NOTE.—In this index the title to principal papers and headings of departments, as *Discussions*, are in italics.]

Abramski, C., *et al.*, on coal, 844
Abstracts—
Alteration associated with ore at Gaspe copper mines (Bell and Scott), 516
Anthophyllite-vermiculite deposit of Hafafit, Eastern Desert, Egypt (Amin and Afia), 317
Blister hypothesis and economic geology (Wolfe), 810
Certain structural features of porphyry copper deposits in the western and southwestern United States (Pennebaker), 122
Certain terms of mining geology as defined and used (Schmitt), 198
Composition of vein-forming fluids from inclusion data (Smith), 205
Copper Cities copper deposit, Globe-Miami district, Arizona (Peterson), 362
Development of monazite exploration techniques (Griffith), 119
Direction of flow of late stage solutions in the Lamaque No. 6 vein (Smith), 530
Edith River uranium deposit (Fisher), 118
Elizabeth copper mine, Vermont (McKinstry and Mikkola), 1
Emerald, Feeney, and Dodger tungsten ore-bodies, Salmo, British Columbia, Canada (Ball), 625
Estimation of reserves for uranium-vanadium deposits on the Colorado Plateau (Bush and Stager), 805
Expense of exploration (Callaway), 328
Explosion pipe in test well on Hicks Dome, Hardin County, Illinois (Brown, Emery, and Meyer), 891
Extraction of uranium from aqueous solution by coal and some other materials (Moore), 652
Formation of intermediate sulfide phases in the solid state (Ross), 734
Friends Station—New Market zinc-bearing area in east Tennessee (Oder), 121
General structural relations of the upper Mississippi Valley zinc-lead district (Heyl), 120
Genesis of the Witwatersrand gold-uranium deposits (Miholić), 537
Geochemical prospecting at Cobalt, Ontario (Koehler, Hostetler, and Holland), 378
Abstracts—Continued
Geologic structure around the Santa Rita, New Mexico, intrusive (Ordonez and Baltosser), 122
Geology and mineralogy of salt and cap rock of U. S. Gulf Coast salt domes (Taylor), 805
Geology and ore deposits of Baja California, Mexico (Wisser), 44
Geology of the Cold Spring tungsten mine, Nederland, Colorado (Ridland), 123
Geology of the Radium Hill uranium mine, South Australia (Parkin and Glasson), 815
Gold pan: A neglected geological tool (Mertie), 639
Human relationships in future mineral procurement (Davidson), 345
Hydrothermal alteration and other characteristics of five explored hot-spring systems (White), 806
Hydrothermal alteration at the Climax molybdenite deposit, Colorado (Vanderwilt and King), 125
Ilmenite deposit of Abu Ghalqa, Egypt (Amin), 77
Investigation of rank in coal by differential thermal analysis (Glass), 294
Investigations of uranium-bearing deposits of the Boulder batholith, Montana (Thurlow and Jarrard), 125
Jersey lead-zinc deposit, Salmo, B. C. (Whishaw), 521
Land-surface subsidence and its relation to the withdrawal of ground water in the Houston-Galveston region, Texas (Winslow and Doyel), 413
Lateritic nickel-cobalt deposit at Moa, Oriente, Cuba (Colligan), 117
Localization of uranium minerals in channel sediments at the base of the Shinarump conglomerate, Monument Valley, Arizona (Witkind), 804
Manganese deposits of the Mogollon Rim, Coconino County, Arizona (Silver), 88
Manganese dioxide for dry cells (Levin, Nye, and Kedesdy), 807
Marginal luminescence of certain intrusive rocks and hydrothermal ore deposits (McDougall), 717
Metallic melting point and ore deposition (Sullivan), 555

Abstracts—Continued
Method for the petrographic analysis of commercially delivered lignite (Traverse), 92
Mineralogy of a uraninite deposit at Caribou, Colorado (Wright), 129
Native copper deposits (Cornwall and White), 808
Notes on the dunite and the geochemistry of vermiculite at the Day Book dunite deposit, Yancey County, North Carolina (Kulp and Brobst), 211
Occurrence and origin of the graphite deposits near Dillon, Montana (Ford), 31
Occurrence of cobalt and nickel in the Silver Summit mine, Coeur d'Alene district, Idaho (Fryklund and Hutchinson), 753
Occurrence of mineral deposits in the pegmatites of the Karibib-Omaruru and Orange River areas of South West Africa (Cameron), 117
Ore controls at the Guadalupe mine, Nuevo Leon, Mexico (Whiting), 493
Ore deposits of Jugoslavia and the development of its mining industry (Schumacher), 451
Origin of salt-dome sulfur deposits (Feely and Kulp), 806
Origin of the Roan Antelope copper deposit of Northern Rhodesia (Davis), 575
Origin of the silica of the bedrock hypogene ore deposits (Schmitt), 877
Origin of vermiculite deposits, Southern Virgin Mountains, Nevada (abstract), 809
Paragenesis of the ores of the Palomas (Hermosa) district, southwestern New Mexico (Jicha), 759
Paragenesis of the zinc-lead-copper deposits at the Mindamar mine, Nova Scotia (Watson), 389
Paragenetic relationships of germanite and reniérite from Tsumeb, South West Africa (Sclar and Geier), 808
Pegmatitic lithium deposits in Canada (Rowe), 501
Petrographic examination of washed, screened and crushed samples of coal from the Sydney and St. Rose coalfields, Nova Scotia (Hacquebard and Lahiri), 837
Preliminary report on replacement and rock alteration in the Soudan iron ore deposit, Minnesota (Schwartz and Reid), 124
Productive ore deposits of the Metaline district (Mills), 121
Progress report on the origin of uranium deposits (Everhart), 118

Abstracts—Continued
Pyritic mineralization in the Goudreau area of Algoma, Ontario (Douglas), 310
Radioactive, pronouncedly differentiated pegmatite sill, Lac La Ronge district, northern Saskatchewan (Mawdsley), 616
Salt-water encroachment as induced by sea-level excavation of Angaur Island (Wentworth, Mason, and Davis), 810
Sedimentary facies of iron-formation (James), 235
Significance of carbonate mineralogy in relation to the uses of carbonate rocks (Graf and Lamar), 809
Structural and stratigraphic control of ore deposition in the Shasta copper-zinc district, California (Kinkel), 120
Structural control of Globe-Miami district, Arizona (Peterson), 122
Structure and mineralization, Silver Bell, Arizona (Richard and Courtright), 123
Studies of factors influencing uranium accumulation in plants (Anderson and Kurtz), 802
Suggested source of the thiophile elements of the Tertiary ore deposits of the southwest (Hillebrand), 863
Systems HgS—Na_2S—H_2O and HgS—Na_2S—Na_2O—H_2O (Dickson and Tunell), 807
Transportation and deposition of quicksilver ores in the Terlingua district, Texas (Thompson), 175
Uranium contents of Wisconsin Rivers and their use in geochemical prospecting (Adams), 803
Uranium deposits, Big Indian Wash-Lisbon Valley area, San Juan County, Utah (Isachsen), 804
Uranium deposits of the Boulder batholith, Montana (Becraft and Pinckney), 803
Uranium exploration, Rum Jungle province, Australia (Sullivan and Fisher), 119
Uranium exploration by the Bureau of Mineral Resources, Geology and Geophysics, in the Rum Jungle province, Northern Territory, Australia (Fisher and Sullivan), 826
Use of the gamma ray scintillation spectrometer in the separate measurement of the uranium and thorium series in geological materials (Hurley), 802
Vertical zoning at the O'Brien gold mine, Kewagama, Quebec (Mills), 423
White Pine copper deposit, Ontonagon County, Michigan (White and Wright), 675

Abstracts—Continued
Widespread occurrence and character of uraninite in the Triassic and Jurassic sediments of the Colorado Plateau (Rosenzweig, Gruner, and Gardiner), 351
Abu Ghalqa, Egypt, The ilmenite deposit of (Amin), 77
Acanthite, 750
Activators, 718
Adams, J. A. S., abstract by, 803
Addresses, human relationships in future mineral procurement (Davidson), 345
Aerial photos, pegmatites in granite, Yellowknife-Beaulieu district, N.W.T., 505
Aerial photos of study areas (communication), 779
Afia, M. S., with Amin, M. S., *Anthophyllite-vermiculite deposit of Hafafit, Eastern Desert, Egypt*, 317
Aggregates, lightweight aphanites (communication), 435
Ajvalija lead-zinc deposit, Yugoslavia, 472
Albite, 404, 508
Albitization, carbonate formation, 245
Aldrich, H. R., on iron, 276
Algoma, Ontario, Pyritic mineralization in the Goudreau area of (Douglas), 310
Allen, E. T., and Day, A. L., on hot springs, 181
on silica, 882
Allen, R. C., on Nonesuch shale, Mich., 689
Alling, H. L., on oolitic iron ores, 256
Almond, H., on cobalt, 756
on tests for cobalt, 383
Alteration, 200, 202
Climax molybdenite deposit, Colo. (abstract), 125
Copper Cities copper deposit, Ariz., 370
Day Book dunite, N. C., 213
Elizabeth mining district, Vt., 22, 28
granite, Salmo tungsten district, B.C., 631
greenstone, Minnesota, Soudan iron deposit (abstract), 124
hot-spring systems (abstract), 806
iron ore wall rock, Mich. (discussion), 440
Majdan Pek copper deposit, Yugoslavia, 476
Palomas district, New Mexico, 763
Pascalis Township, Que., 721
rocks, southwestern U. S., 878
Salmo district, B.C., 524
Silver Belt, Idaho, 754
solutions, ore fluid, and magmas, 871
spodumene, 504, 507
uraninite, Colo. Plateau, 360
uraninite deposit, Caribou, Colo., 130, 134, 146
vermiculitization, Nevada (abstract), 809
Alteration associated with ore at Gaspe copper mines (Bell and Scott), 516
Alty, S. W., on tourmaline, 604
Alunite, 401
Amblygonite, 501, 504
Arizona, pegmatite belt (review), 335
Amin, M. S., *Ilmenite deposit of Abu Ghalqa, Egypt*, 77–87
Amin, M. S., and Afia, M. S., *Anthophyllite-vermiculite deposit of Hafafit, Eastern Desert, Egypt*, 317–327
Amphibolite, 11
Analysis, Investigation of rank in coal by differential thermal (Glass), 294
Anderson, C. A., on conglomerates, 50
Anderson, C. S., on copper, 2
Anderson, R. J., on Silver Belt, Idaho, 754
Anderson, R. Y., and Kurtz, E. B., abstract by, 802
Andesite, 436
Anglesite, 772
Angaur Island, salt-water encroachment (abstract), 810
Ankerite, 316, 604
Ankeritization, 879
Anomalies, geochemical, Cobalt, Ont., 384
Anthophyllite, 217
Anthophyllite-vermiculite deposit of Hafafit, Eastern Desert, Egypt (Amin and Afia), 317
Anthracite, meta-anthracite, 296
uranium extraction, 654
Anthraxylon, 93, 99
Antimony, deposition, 560
Yugoslavia, 454, 478
Antiquity, Roman mining in Yugoslavia, 453
Apatite, 604, 898, 901
Aphrosiderite, 265
Apuli, W. E., analysis by, 263
Aquifers, overburden support and pressure relief, 418
withdrawal and compaction, Texas (discussion), 790
Archean, uranium concentration by organisms, 538
Argentite, 161, 170, 762, 769, 771, 774
Arizona, Copper Cities copper deposit, Globe-Miami district (Peterson), 362
Manganese deposits of the Mogollon Rim, Coconino County (Silver), 88
copper, Silver Bell, structure and mineralization (abstract), 123
ore deposits, thiophile elements, 867
pegmatites, White Picacho district (review), 335
Ray copper deposit, genesis, 572
rocks, alteration, 878
structure, Globe-Miami district (abstract), 122
uraninite deposits, 352
uranium, Monument Valley (abstract), 804

Arkansas, anthracite, thermal curves, 297, 299
Armstrong, F. C., and Full, R. P., on Crystal graphite mine, Mont., 34
Arsenic, Alšar deposit, Yugoslavia, 478
Arsenic and native copper (communication), 908
Arsenopyrite, 71
Asbestos, Yugoslavia, 489
Asphaltite, 358
Atmosphere, composition during geologic time, 244
Attia, M. I., on hematite, 77
Auger, P. E., on ores, 723
on sulphides, 423
Australia, Uranium exploration by the Bureau of Mineral Resources, Geology and Geophysics, in the Rum Jungle province, Northern Territory (Fisher and Sullivan), 826
Central Australia, copper-nickel, Macdonnell Range, 570
copper, Cobar deposit, 561
New South Wales, Broken Hill area (discussion), 783
uranium, Edith River deposits (abstract), 118
origin, Rum Jungle district, 563
Radium Hill mine, 815
Rum Jungle province (abstract), 119
Western Australia, copper-nickel region (discussion), 904
iron formations, 257
Austria, anthracite, Leoben, thermal curve, 297
Autunite, 832
Avala lead-zinc deposit, Yugoslavia, 469
Axelrod, J. M., identification by, 756
Ayer, F. A., on White Pine mine, Mich., 677
Ayres, V. L., on stilpnomelane, 270

Bacteria, iron, nitrogen, and sulfur fixation (review), 104
mineral deposit formation, 538
petroleum microbiology (review), 912
sulphide precipitation, 611
sulphur production from dissolved sulphate (abstract), 806
Bain, G. W., radiometric test by, 899
Baja California, Mexico, Geology and ore deposits of (Wisser), 44
Balkan Peninsula, mineral deposits, 455, 457
Ball, C. W., *The Emerald, Feeney, and Dodger tungsten ore-bodies, Salmo, British Columbia, Canada*, 625–638
Ball, J., on Hafafit Range, Egypt, 317
Baltosser, W. W., with Ordonez, G., abstract by, 122
Banding, sulphide ore, Mindamar mine, Nova Scotia, 408
uraninite ores, Colo., 162
Barbosa, O., on an unconformity, 659
Barghoorn, E. S., and Spackman, W., on lignite, 93
Barite, 401, 496, 766, 901
Barnes, R. S., on copper, 564
Barshad, I., on vermiculite, 218
Barthoux, J., on granite, 77
Basalt, 436
Bassett, A. B., on clays, 181
Bastin, E. S., on argentite, 771
on colloform texture, 162
on graphite, 34
Bastin, E. S., and Hill, J. M., on quartz monzonite, 131
Bastin, E. S., and Laney, F. B., on lead-silver sulphide, 768
Batêa, 644, 646
Bateman, A. M., on ores, 85, 591
on sulphides, 749
on terms, 198
review of book by, 338, 547
Bateman, A. M., and Lasky, S. G., on covellite, 735
Batholith, 199, 203
Baja Calif. batholith, Mexico, 47, 56
Boulder batholith, uranium deposits, Mont. (abstract), 803
Batteries, manganese dioxide for dry cells (abstract), 807
Bauxites, Northern Ireland, Antrim (review), 108
Yugoslavia, 454, 486
Bay, H. X., and Du Bois, E. P., on Fricker well, Ill., 893
Bayley, W. S., on slate, 248
Beal, C., on Baja Calif., Mexico, 46
Becker, G. F., on saprolite, 641
Becquerelite, 804
Becraft, G. E., and Pinckney, D. M., abstract by, 803
Beers, R. F., and Goodman, C., on uranium, 538
Beerstecher, E., Jr., review of book by, 912
Belgian Congo, copper-cobalt-uranium belt (discussion), 904
renierite, Kipushi mine, 563
Belgium, ottrelite schists, Stavelot massif, 314
Bell, A. M., and Scott, F. J., *Alteration associated with ore at Gaspe copper mines*, 516–520
Bell, P. L., and Mackenzie, H. B., on gold, 69
Benson, C. B., Wangaard, J. C., and Johnson, H. A., on copper, 3
Bentonite, uranium extraction, 654, 656
Berek, M., review of book by, 224
Berthoud, E. L., on uranium, 652
Beryl, 506, 512, 912
Arizona, Midnight Owl mine (review), 336
New England pegmatite deposits (review), 793

Beryl—*Continued*
South West Africa, pegmatite deposits (abstract), 117
Berz, K. C., on melnikowite, 258
Beveridge, W. I. B., on ideas, 877
Beyschlag, F., Vogt, J. H. L., and Krusch, P., on Idria mercury deposit, Yugoslavia, 479
Bibliography, anthophyllite-vermiculite deposit, Hafafit, Egypt, 327
aphanitic igneous rocks for aggregates, 438
C. enigmaticum and isotopes, 543
coal, Nova Scotia, 862
coal rank and thermal analysis, 309
cobalt, geochemical prospecting, Cobalt, Ont., 387
cobalt-nickel occurrences, Silver Summit mine, Idaho, 758
Copper Cities area, Ariz., 377
copper deposit, White Pine, Mich., 716
Day Book dunite mass, N. C., 220
Elizabeth copper mining district, Vt., 30
geology and ore deposits, Baja Calif., Mexico, 74
gold, O'Brien mine, Que., 430
gold pan and panning, 651
gold-uranium, genesis, Witwatersrand, 540
graphite, Dillon, Mont., 43
ground water withdrawal and surface subsidence, Texas, 422
Guadalupe mine, Mexico, 500
Hicks Dome area, Ill., 902
ilmenite deposit, Abu Ghalqa, Egypt, 87
inclusion fluids, composition, 210
lignite, petrography, N. Dakota, 100
lithium pegmatite deposits, Canada, 515
luminescence of rocks, 726
magnetite, authigenic origin, 102
mercury deposition, Terlingua, Texas, 196
Mindamar mining district, Nova Scotia, 411
mineral deposits, Yugoslavia, 490
mining camps of the West (review), 443
ore deposition and metallic melting points, 574
ore-forming fluid, 733
ores, Palomas district, New Mexico, 778
pyrite deposits, Goudreau, Ont., 316
Roan Antelope copper deposit, Northern Rhodesia, 614
scheelite, Little Cottonwood stock, Utah (communication), 223
sedimentary facies of iron formations, 281
silica of ore deposits, 890
solution flow, Lamaque No. 6 vein, Que., 536
sulphide phases formation, 751
terms of mining geology, 204
thiophile elements of ore deposits, 876
Bibliography—*Continued*
tungsten ore bodies, Salmo, B. C., 638
uraninite deposits, Colo. Plateau, 361
uraninite ore, Caribou, Colo., 173
uranium extraction by materials, 658
Bieberite, 356, 756
Billings, M. P., on metamorphism, 5
review of book by, 913
Billingsley, P., and Locke, A., on copper, 73
Biographies, American science leaders (review), 443
Biotite, 12, 22, 138, 147, 619, 809, 822
Birch, F., and Bancroft, D., on basalt, 865
Bischoff, C. T., on geochemical anomalies, 387
Bismodigenite, 750
Bismuth, melting point and occurrence, 562
Bitumen in inclusions, 209
Blanchard, R., on banding, 409
Blanchard, R., and Hall, G., on layering, 409
Boehmite, 488
Boese, E., and Wittich, E., on Cretaceous, Baja Calif., Mexico, 55
Bonanza Trail, ghost towns and mines (review), 442
Books received, 109, 227, 340, 444, 548, 666, 796, 914
Bor copper deposit, Yugoslavia, 473
Borchert, H., on copper, 737
Bornite, 588, 591, 593, 611, 695, 737, 740, 768
Boswell, K. C., with Czech, H., translation by, 227
Boudinage, 25, 26
Boutwell, J. M., on uranium, 652
Bowen, N. L., and Tuttle, O. F., on serpentinization, 214
on talc, 775
Boyd, J., analysis by, 216
Boydell, H. C., on colloform textures, 162
Brannock, W. W., *et al.*, on hot springs, 181
Braune, H., on diffusion, 740
Brazil, iron, Congonhas district (discussion), 659
itabirites, 240, 257
Breccia, 200, 203
Brazil, Congonhas district (discussion), 660
Guadalupe mine, Mexico, 498
Hicks Dome, Illinois, 891, 893, 901
ore and rock, Elizabeth mine, Vt., 22, 26
Trepca ore deposit, Yugoslavia, 462
Breger, I. A., on vacuum technique, 295
Breger, I. A., and Deul, M., on uranium, 657
Breger, I. A., and Whitehead, W. L., on coal, 657
Bresovica chromite district, Yugoslavia, 483

British Columbia, Canada, The Emerald, Feeney and Dodger tungsten orebodies, Salmo (Ball), 625
The Jersey lead-zinc deposit, Salmo (Whishaw), 521
Coast Range batholith, 61
Brobst, D. A., with Kulp, J. L., *Notes on the dunite and the geochemistry of vermiculite at the Day Book dunite deposit Yancey County, North Carolina*, 211
Broderick, T. M., on arsenic, 911
on magnetite, 247
Broggi, J. A., editorial by, 431
Brombert, B. A., reviews by, 107, 665
Brooker, E. J., and Nuffield, E. W., on uraninite, 169
Brown, J. S., on hydrothermal solutions, 557
on magnetite, 258
Brown, J. S., Emery, J. A., and Meyer, P. A., Jr., *Explosion pipe in test well on Hicks Dome, Hardin County, Illinois*, 891–902
Brown, R. A., on O'Brien mine, Que., 423
Brown, W. L., on ore, 724
on ore bodies, 407
Bruce, E. L., on gold-silver ratios, 427
on pyrite, 312
Brujewicz, S. W., on iron oxides, 274
Bucher, W. H., on cryptovolcanic structures, 895
Buddington, A. F., on gold, 58
Buerger, M. J., and Buerger, N. W., on sulphides, 735
Buerger, N. W., on copper, 735
Buerger, N. W., and Buerger, M. J., on chalcopyrite, 737
Building stones, staining (abstract), 809
Bureau of Mineral Resources, Geology and Geophysics in the Rum Jungle province, Northern Territory, Australia, Uranium exploration by the (Fisher and Sullivan), 826
Burfoot, J. D., on talc, 775
Bush, A. L., and Stager, H. K., abstract by, 805
Butler, B. S., on ore deposits, 875
Butler, B. S., and Vanderwilt, J. W., on molybdenite, 222
Butler, B. S., *et al.*, on copper, 677, 908
Butler, B. S., *et al.*, on pyrite, 357
Butler, R. D., on sphalerite, 410
Byerly, P., on Sierra Nevada batholith, Calif., 58

Cadmium, melting point and zoning, 557
Cady, W. M., McKelvey, V. E., and Wells, F. G., on iron, 279
Caillère, S., and Kraut, F., review of memoir by, 441
Calabash, 645
Calcite, 133, 137, 138, 762, 766
inclusion stability (discussion), 787
uranium extraction, 654
California, copper-zinc, Shasta district, structural controls (abstract), 120
mineral deposits, Sierra Nevada batholith, 58
subsidence by oil and water withdrawals, 419, 420
Sulphur Bank hot springs (abstract), 807
Calkins, F. C., on banding, 408
Calkins, F. C., and Butler, B. S., on quartz monzonite, 221
Callaway, H. M., *Expense of exploration*, 328–330
Calomel, 179
Cameron, E. N., abstract by, 117
Cameron, E. N., *et al.*, on lithium, 502
on pegmatitic fluid, 218
review of professional paper by, 792
Camsell, C., mining industry, Canada (review), 547
Canada, Pegmatitic lithium deposits in (Rowe), 501
mineral industry (review), 547
uranium, Lake Athabaska deposit, origin, 563
Canfield, F. A., Hillebrand, W. F., and Schaller, W. T., on mosesite, 179
Cannel coal, uranium extraction, 654
Carbon, isotopes (discussion), 542
Carbon dioxide, occurrence in inclusions, 331
Carbon dioxide in inclusions, 207
Carbonate veins, Goudreau area, Ont., 315
Carbonates, 461
iron formation facies, 236, 251, 272
Mindamar mining district, Nova Scotia, 395
ore shale, Roan Antelope copper deposit, Northern Rhodesia, 603
Carbonatization, 881
Carbonatization of diabase dikes, Mindamar mine, Nova Scotia, 405
Caribou, Colorado, Mineralogy of a uraninite deposit at (Wright), 129
Carnotite, 360, 804
Cassiterite, South West Africa, pegmatite deposits (abstract), 117
Castaño, J. R., and Garrels, R. M., on iron oxide, 256
on sea water, 180
Cat Lake—Winnipeg River lithium pegmatites, Manitoba, 507
Catalyst, clay and mercury deposition, 193, 195
Cayeux, L., on ooliths, 256
Cerussite, 772
Chalcedony, 159, 160
cinnabar in chalcedony, 195

Chalcocite, 123, 358, 368, 374, 475, 588, 591, 594, 598, 611, 676, 702, 735, 749, 769
Chalcopyrite, 1, 11, 21, 27, 120, 123, 159, 357, 358, 362, 367, 374, 402, 407, 410, 474, 588, 591, 592, 607, 610, 696, 737, 762, 768, 774
Chalcopyrrhotite, 737
Chamosite, 265
Charcoal, uranium extraction, 654
Charnockites (review), 338
Chemical composition, altered rock, Caribou, Colo., 142
anthophyllite and vermiculite, Egypt, 325
bauxites, Yugoslavia, 489
coal, Nova Scotia, 839, 851
cobalt content of soils, Cobalt, Ont., 381
feldspar, Saskatchewan, 620
feldspar concentrate, Que., 514
fluorite, Hicks Dome, Ill., 898
ilmenite ore and gabbro, Egypt, 86
iron formations, 250, 271
ore, Palomas district, New Mexico, 776
Trepča lead-zinc deposit, Yugoslavia, 464
rocks, Day Book dunite mass, N. C., 216
Needle Mtn., Gaspe, Que., 518
southwestern U. S., 878
schist, Mindamar area, Nova Scotia, 394
uraninite, Colo., 169
Chemical industries, mineral needs (review), 913
Chemistry, silicates (review), 546
textbooks (reviews), 107, 794
Chert, 238, 273
Chisholm, E. O., on zinc, 387
Chlorite, 136, 261, 265, 401, 440
Chromite, 49
Day Book dunite mass, N. C., 215, 216
Yugoslavia, 454, 481
Cinnabar, 176, 188, 479, 807
Cissarz, A., on mineral deposits, 455
Clarain, 855
Clarke, F. W., on rocks, 888
Clarke, O. M., on diabase, 572
Clarodurain, 848
Claussen, C. H., Driesen, A., and Rösch, S., review of book edited by, 224
Clausthalite, 356
Clay, mercury deposition by clays, 192
Cleavelandite, 501, 504, 508
Cloos, H., on grabens, 64
review of translated book by, 224
Coal, Great Britain (review), 665
Yugoslavia, 454
Coal and some other materials, Extraction of uranium from aqueous solution by (Moore), 652
Coal by differential thermal analysis, Investigation of rank in (Glass), 294
Coal from the Sydney and St. Rose coalfields, Nova Scotia, Petrographic examination of washed, screened and crushed samples of (Hacquebard and Lahiri), 837
Coalification, 307
Cobalt, 564, 569
occurrence in uraninite deposits, Colo. Plateau, 356
lateritic ores, Cuba (abstract), 117
Cobalt, Ontario, Geochemical prospecting at (Koehler, Hostetler, and Holland), 378
Cobalt and nickel in the Silver Summit mine, Coeur d'Alene district, Idaho, The occurrence of (Fryklund and Hutchinson), 753
Cobalt bloom, 756
Coefficient of diffusion, 742
Coeur d'Alene district, Idaho, The occurrence of cobalt and nickel in the Silver Summit mine (Fryklund and Hutchinson), 753
Coffinite, 356
Colligan, R. V., abstract by, 117
Collins, W. H., and Quirke, T. T., on ottrelite, 314
Collins, W. H., Quirke, T. T., and Thomson, E., on iron formation, 276
Colloform textures of carbonates, 395, 407
Colloids, mercury sulphide, 191, 195
silica (review), 546
Colorado, Mineralogy of a uraninite deposit at Caribou (Wright), 129
coal, thermal curves, 297
Front Range mineral belt, 866
tungsten, Cold Spring mine (abstract), 123
uraninite deposits, Colo. Plateau, 351
uranium, Central City deposit, origin, 731
uranium in coal, 652
Colorado Plateau, Widespread occurrence and character of uraninite in the Triassic and Jurassic sediments of the (Rosenzweig, Gruner, and Gardiner), 351
ore deposits, genesis, 568
uranium and fossil wood, 652
uranium-vanadium field (discussion), 904
reserves (abstract), 805
Columbite, 506
Arizona, Midnight Owl mine (review), 336
South West Africa, pegmatite deposits (abstract), 117
Communications—
Aphanitic igneous rocks, a new source of bloated lightweight aggregate (Riley), 435
Arsenic and native copper (Drier), 908
Disseminated scheelite in the Little Cottonwood stock, Utah (Erickson and Sharp), 221

Communications—Continued
Low temperature authigenic magnetite, Friedman, 101
Use of aerial photographs for the graduate thesis (Ruff), 779
Concentrates, processing, 650
Conley, J. E., *et al.*, on aggregates, 435
Continents, history (review), 105
Cooke, H. C., James, W. F., and Mawdsley, J. B., on ore bodies, 407
Copper, Arizona, Globe-Miami district, structure (abstract), 122
Silver Bell, structure and mineralization (abstract), 123
Baja Calif. deposits, Mexico, 44, 67, 69, 72
California, Shasta district (abstract), 120
deposition temperature, 561
native copper and arsenic (communication), 908
native copper deposits (abstract), 808
occurrence in rocks, 864, 866
Ontario, Sudbury basin (review), 442
Rum Jungle area, Northern Territory, 831
sulphide phases, formation, 734
United States, porphyry deposits, structure (abstract), 122
Yugoslavia, 454, 473
Copper Cities copper deposit, Globe-Miami district, Arizona (Peterson), 362
Copper deposit, Ontonagon County, Michigan, The White Pine (White and Wright), 675
Copper deposit of Northern Rhodesia, The origin of the Roan Antelope (Davis), 575
Copper deposits at the Mindamar mine, Nova Scotia, Paragenesis of the zinc-lead (Watson), 389
Copper mine, Vermont, The Elizabeth (McKinstry and Mikkola), 1
Copper mines, Alteration associated with Gaspe (Bell and Scott), 516
Cordierite, 506
Cornwall, H. R., and White, W. S., abstract by, 808
Corundum, 218
Corycium enigmaticum, 538
Creasey, S. C., on banding, 409
Counter and scintillation equipment, 149
Courtright, J. H., with Richard, K., abstract by, 123
Covellite, 358, 368, 474, 735, 762, 769
Craig, H., on carbon, 541
Cretaceous, Baja Calif., Mexico, 52
Crickmay, C. H., on Juro-Sonora land, 52
Cryoluminescence, 719, 722
Cryptovolcanic structures, 891, 895
Cuba, lateritic nickel-cobalt ore (abstract), 117
Cubanite, 21, 737
Cupola, 199, 203
Cuprodigenite, 739
Czech, H., and Boswell, K. C., review of book translated by, 227

Dacite, 436
Dake, C. L., on pre-St. Peter sediments, 893
Daly, R. A., on igneous rocks, 879, 882
on composition, 436
on terms, 199
on isostatic compensation, 867
Daniels, F., and Saunders, D. F., on luminescence, 718
Davidite, 815, 822
Davidson, C. F., on uraninite, 537
Davidson, C. F., and Bowie, S. H. U., on asphaltite, 359
on thucholite, 537
on uranium, 652
Davidson, D. M., *Human relationships in future mineral procurement*, 345–350, discussion, 906
on bornite, 595
Davis, G. R., *The origin of the Roan Antelope copper deposit of Northern Rhodesia*, 575–615
Davis, R. E., and Foote, F. S., on direct transfer method, 781
Davis, W. M., review of essays by, 914
Davy, H., on inclusions, 207
Day Book dunite deposit, Yancey County, North Carolina, Notes on the dunite and the geochemistry of vermiculite at the (Kulp and Brobst), 211
De Weisse, J. G., on bauxite, 487
Deans, T., on Kupferschiefer, 714
Decrepitation, inclusions in quartz, Que., 530
Denson, N. M., Bachman, G. O., and Zeller, H. D., on uranium, 652
Deposit, Ontonagon County, Michigan, The White Pine copper (White and Wright), 675
Deposition, Metallic melting point and ore (Sullivan), 555
Deposition of quicksilver ores in the Terlingua district, Texas, Transportation and (Thompson), 175
Deposits, Genesis of the Witwatersrand gold-uranium (Miholić), 537
The marginal luminescence of certain intrusive rocks and hydrothermal ore (McDougall), 717
The origin of the silica of the bedrock hypogene ore (Schmitt), 877
Deposits at the Mindamar mine, Nova Scotia, Paragenesis of the zinc-lead-copper (Watson), 389
Derby, O. A., on the batêa, 645
Derry, D. R., on spodumene, 513
Derry, D. R., and Hertz, H. C., on pyrite, 724
Descloizite, 772
Desjardins, L., on floating line method, 782
Deuchar, J., on inclusions, 206

Déverin, L., on ironstones, 279
Dewey, H., and Flett, J. S., on cherty sediments, 277
Dextral fold, 17
Diabase, dikes, Mindamar mine, Nova Scotia, 403
Diagenesis, 274
Diagrams—
alpha activity of rock, Colo., 132
alteration zones, Day Book dunite, N. C., 215
analyses, iron silicates, 266
auger, 381
batêa and gold pan, 646
coal, petrographic analyses, Nova Scotia, 846
copper content of sediments, White Pine, Mich., 697
ilmenite ore and gabbro, 80
inclusion fluids, pressure relations, 788
ore bodies, Radium Hill mine, South Australia, 823
oxides, heat of formation, 903
oxides suitable for bloating, 436
petrographic constituents, lignite, N. Dakota, 94
pyrite mass, Goudreau area, Ont., 313
radioactivity of small batholiths, 719
schist in sulphides, 22, 26
sial and metallic segregations, migration, 870
structure of lithium pegmatites, Man., 509
sulphide phases in solid state, formation, 743
sulphide zoning, Roan Antelope copper belt, Northern Rhodesia, 588, 590
thermal curves, coal, 297, 305
Vein No. 6, Lamaque mine, Que., 531
water flow along a barrier, 186
Diamonds (review), 664
Diatoms, kaolin formation, 538
Diatremes, 200, 203, 896
Dickson, F. W., and Tunell, G., abstract by, 807
Dictionary, mineralogical terms (review). 338
mining terms (review), 443
Differentiation, deuteric differentiation. Utah, 731
Diffusion, 206
arsenic into copper (communication). 909
metals, 564, 568
sulphides and chalcocite, 734, 741
Digenite, 735, 740
Dikes, Abu Ghalqa area, Egypt, 80, 84
Alamo district, Baja Calif., Mexico, 68
chromite districts, Yugoslavia, 481
Copper Cities area, Ariz., 365
diabase, Mindamar mine, Nova Scotia, 389, 397, 403, 411
Dikes—*Continued*
Egypt, Hafafit area, 320
Elizabeth copper mine, Vt., 16
Guadalupe mine, Mexico, 493, 495
Hicks Dome area, Illinois, 895
Montana, Boulder batholith (abstract), 125
Palomas district, New Mexico, 777
Pascalis Township, Que., 721
Salmo district, Brit. Columbia, 523, 628, 630
Silver Bell district, Arizona (abstract), 123
uranium near bostonites, Colo., 731
Dillon, Montana, Occurrence and origin of the graphite deposits near (Ford), 31
Dimitrijević, B., on Avala district, Yugoslavia, 469
Diopside, 16, 517
Discussions—
Comments on the iron deposits of the Congonhas district, Minas Gerais, Brazil (Guild), Dorr, 659
Geology of Australian ore deposits: Broken Hill (King, H. F., *et al.*), Gustafson, 783
Human relationships in future mineral procurement (Davidson), Just, 906
Land-surface subsidence and its relation to the withdrawal of ground water in the Houston-Galveston region, Texas (Winslow and Doyel), Pratt, 790
Metallic melting point and ore deposition (Sullivan), 903, 904
Origin of soft iron ores of Michigan—A reply (Mann), 439
Sedimentary facies of iron formation (James), Percival, 905
Some considerations regarding liquid inclusions as geologic thermometers (Skinner), Smith, 331; (Skinner), Richter and Ingerson, 786
What killed *Corycium enigmaticum?* (Craig), (Jensen), Rankama, 541
Djakovica chromite district, Yugoslavia, 483
Dolomite, 390, 395
calcination (abstract), 809
Dome, 203
Donath, M., on copper, 476
Donnay, J. D. H., Nowacki, W., and Donnay, G., review of book by, 663
Dorr, J. V. N., II, discussion by, 659
on sediments, 257
Dorr, J. V. N., II, Guild, P. W., and Barbosa, A. L. M., on iron, 659
Douglas, G. V., *Pyritic mineralization in the Goudreau area of Algoma, Ontario,* 310–316
Doyel, W. W., with Winslow, A. G., *Land-surface subsidence and its relation to the withdrawal of ground water in the Houston-Galveston region, Texas,* 413

Dreyer, R. M., on cinnabar, 180
Drier, R. W., communication by, 908
Drilling, lithium pegmatites, Que., 513
Rum Jungle area, Northern Territory, 835
du Preez, J. W., on ferric oxide, 246
Dulong, 645
Dunham, R. J., review by, 441
Dunite and the geochemistry of vermiculite at the Day Book dunite deposit, Yancey County, North Carolina, Notes on the (Kulp and Brobst), 211
Dunn, J. A., discussion by, 332
on iron formations, 276
Durham, J. W., on Occidentalia, 63
Dutton, C. E., on slate, 248

Eardley, A. J., on Jurassic, 50
Earth, population and production (review), 339
travel narrative (review), 224
Ebbutt, F., on gold, 536
Economic geology, neglected fundamentals (editorial), 431
Editorials—
Some neglected fundamental practices of economic geology (Broggi), 431
Edwards, A. B., on banding, 409
on iron, 257
Egypt, Anthophyllite-vermiculite deposit of Hafafit, Eastern Desert (Amin and Afia), 317
The ilmenite deposit of Abu Ghalqa (Amin), 77
Einstein equation, 748
Eisenmann, L., on chalcocite, 747
Eitel, W., review of book by, 546
Elements of the Tertiary ore deposits of the southwest, A suggested source of the thiophile (Hillebrand), 863
Elizabeth copper mine, Vermont (McKinstry and Mikkola), 1
Elliot, C. D., on coke, 842
Emeléus, H. J., *et al.*, on hydrous minerals, 729
Emery, J. A., with Brown, J. S., and Meyer, P. A., Jr., *Explosion pipe in test well on Hicks Dome, Hardin County, Illinois*, 891
Emery, K. O., and Rittenberg, S. C., on pH and depth of burial, 275
Emmons, S. F., and Merrill, G. P., on structure, Baja Calif., Mexico, 65
Emmons, W. H., on ferric sulphate, 777
on gold, 429
on ore solutions, 873
Enargite, 474
Engel, A. E. J., on talc, 400
Enrichment, copper, Copper Cities deposit, Ariz., 374
Majden Pek copper district, Yugoslavia, 477
ores, Palomas district, New Mexico, 774
Entwistle, L., analyses by, 878
Epidote, 722
Epsomite, 773, 777
Erickson, M. P., and Sharp, B. J., communication by, 221
Erlenmeyer, H., and Gärtner, H., on hydrous minerals, 729
Erythrite, 756
Escher, B. G., on grabens, 64
Eskola, P., on greenschist facies, 245
on skarn, 633
Eskola, P., Vuoristo, U., and Rankama, K., on carbonate, 245
Ethmolith, 200, 203
Everhart, D. L., abstract by, 118
on uraninite, 168
Everhart, D. L., and Wright, R. J., on uraninite, 166
Exinite, 847
Expense of exploration (Callaway), 328
Experiments, bloating tests on igneous rocks, 436
differential thermal analysis of coal, 295
inclusions in quartz, filling or leakage (discussion), 786
sulphide phases formation in solid state, 738, 744
uranium extraction by materials, 653
Exploration, Expense of (Callaway), 328
Exploration by the Bureau of Mineral Resources, Geology and Geophysics in the Rum Jungle province, Northern Territory, Australia, Uranium (Fisher and Sullivan), 826
Explosion pipe in test well on Hicks Dome, Hardin County, Illinois (Brown, Emery, and Meyer), 891
Exsolution intergrowths, ilmenite and hematite, Egypt, 83, 86
Eyles, V. A., review of memoir by, 108

Fairchild, J. G., analysis by, 271
Falkmanite, 738
Faults, 883
Baja Calif., Mexico, 44, 64
Brazil, Congonhas district (discussion), 660
Cobalt district, Ont., 379
Copper Cities area, Ariz., 364
Elizabeth copper mine, Vt., 18
Guadalupe mine, Mexico, 493, 495
Hicks Dome area, Illinois, 894
New Mexico, Santa Rita intrusive (abstract), 122
ottrelite schists near faults, 314
Palomas mining district, New Mexico, 761
Rum Jungle area, Northern Territory, 830
Salmo tungsten district, B. C., 525, 625, 628
Silver Summit mine, Idaho, 755, 757
Upper Miss. Valley zinc-lead district (abstract), 120

Faults—*Continued*
White Pine district, Mich., 691, 706
Yugoslavia, 459, 472, 479, 481
Feely, H. W., and Kulp, J. L., abstract by, 806
Feigl, F., on cobalt, 756
Feldspar, 508, 513, 618, 641, 648
Arizona, pegmatite belt (review), 335
Fenner, C. N., on silica, 882
Ferberite, 124
Fertilizer, uranium content, Wisconsin (abstract), 803
Fick's Law, 745
Finland, *Corycium enigmaticum*, 538
Finnell, T. L., on replacement, 358
Fischbeck, K., and Dorner, O., on copper, 748
Fischer, R. P., on Morrison formation, 353
Fischer, R. P., and Hilpert, L. S., on uranium, 652
Fisher, J. C., Hollomon, J. H., and Turnbull, D., on water, 193
Fisher, M. S., on gold, 430
Fisher, N. H., abstract by, 118
on gold, 426
on silver, 560
Fisher, N. H., and Sullivan, C. J., *Uranium exploration by the Bureau of Mineral Resources, Geology and Geophysics, in the Rum Jungle province, Northern Territory, Australia*, 826–836
Fisher, N. H., with Sullivan, C. J., abstract by, 119
Fjords, black mud deposition, Norway, 539
Flett, J. S., and Hill, J. B., on anthophyllite, 326
Flow of late stage solutions in the Lamaque No. 6 vein, Direction of (Smith), 530
Flowage of sulphides, Nova Scotia, 409, 410
Fluids at various stages—A suggested approach, Nature of the ore-forming (Ingerson), 727
Fluids from inclusion data, Composition of vein-forming (Smith), 205
Fluorite, 222
Hicks Dome, Illinois, 897
Folding, incompetent layer shearing, 312
Roan Antelope copper belt, Northern Rhodesia, 584
Folds, Baja Calif., Mexico, 55
Brazil, Congonhas district (discussion), 660
Broken Hill area, New South Wales (discussion), 785
Cobar copper deposit, New South Wales, 561
Elizabeth mine, Vt., 8, 17
Needle Mtn., Gaspe, Que., 516
Radium Hill district, South Australia, 818
Roan Antelope copper belt, Northern Rhodesia, 578
Folds—*Continued*
Salmo district, Brit. Columbia, 521, 524, 628
synclines, Vermont, 3
Upper Miss. Valley zinc-lead district (abstract), 120
White Pine district, Mich., 691
Yugoslavia, 466, 472, 481
Ford, R. B., *Occurrence and origin of the graphite deposits near Dillon, Montana*, 31–43
Forgan, C. B., on Trepča area, Yugoslavia, 462
Formation of intermediate sulfide phases in the solid state (Ross), 734
Formulas, Bernoulli theorem, 178
cost of exploration, 329
pegmatite reaction with olivine, 219
sulphide phase, 741
talc formation from dolomite, 775
waters, interface slope, 185
Fortier, Y. O., on Yellowknife-Beaulieu region, N.W.T., 504
Fossils (review), 107
Fourmarier, P., review by, 103
Fractional panning, 650
Fractures, Radium Hill uranium mine, South Australia, 821, 824
Yugoslavia, 459
France, iron, Lorraine basin (review), 441
Frederickson, A. F., on bentonite, 656
Freeman, O. W., and Martin, H. W., review of book by, 794
French Guinea, iron, Conakry deposit, 905
Freudenberg, W., on iron, 67
Freundlich, H., on ions, 152
Friedensburg, F., on Yugoslav mining industry, 454
Friedman, I., on solutions, 210
Friedman, S. A., communication by, 101
Fries, C., and Schmitter, E., on pegmatites, 47
Frueh, A. J., Jr., on bornite, 740
Fryklund, V. C., Jr., and Hutchinson, M. W., *The occurrence of cobalt and nickel in the Silver Summit mine, Coeur d'Alene district, Idaho*, 753–758
Fuchsite, 723
Fusain, 99, 838, 841, 857
Fyfe, W. S., on atomic bonds, 565

Gabb, W. M., on conglomerates, 50
Galena, 21, 71, 155, 157, 222, 368, 402, 461, 471, 496, 526, 539, 762, 765, 768
Galliher, E. W., on sulphuretum, 242
Galveston region, Texas, Land-surface subsidence and its relation to the withdrawal of ground water in the Houston (Winslow and Doyel), 413
Gardiner, L., with Rosenzweig, A., and Gruner, J. W., *Widespread occurrence and character of uraninite in the Triassic and Jurassic sediments of the Colorado Plateau*, 351

Garlick, G. F. J., on luminescence, 719
Garlick, W. G., and Brummer, J. J., on granites, 570
on Roan Antelope copper belt, Northern Rhodesia, 576
Garnet, 7, 11, 23, 35
Garrels, R. M., and Dreyer, R. M., on diffusion, 565
Garrels, R. M., Jones, C. L., and Howland, A. L., on a circulation apparatus, 653
on solutions, 653
Garside, E. B., review of translation by, 224
Gas, mercury deposition from gases, 184, 189
Gaspe copper mines, Alteration associated with ore at (Bell and Scott), 516
Geijer, P., on oxide sediments, 257
Gems and pearls (review), 663
Genesis, copper ores, Roan Antelope deposit, Northern Rhodesia, 609, 611
Vermont, 5
gold-quartz, Pacific belt, 57, 59, 61
ilmenite deposit, Abu Ghalqa, Egypt, 84
ore bodies and dikes, Nova Scotia and Que., 407
ore deposits and blister hypothesis (abstract), 810
ore deposits and metallic melting points, 568
Genesis of the Witwatersrand gold-uranium deposits (Miholić), 537
Geochemical prospecting, Rum Jungle area, Northern Territory, 835
uranium content of rivers, Wis. (abstract), 803
Geochemical prospecting at Cobalt, Ontario (Koehler, Hostetler, and Holland), 378
Geochemistry, corundum, 218
definition, 202
gold, solubility and enrichment, 429
mineralizing fluids, 884
ore-forming fluids, 727
oxyphile elements (discussion), 903
system HgS—Na_2S—H_2O (abstract), 807
textbook (review), 666
uranium, accumulation in plants (abstract), 803
uranium in rivers, Wisconsin (abstract), 803
Geochemistry of vermiculite at the Day Book dunite deposit, Yancey County, North Carolina, Notes on the dunite and the (Kulp and Brobst), 211
Geography, Baja California, 46
essays by W. M. Davis (review), 914
North America (review), 665
Pacific Northwest (review), 794
Geologic history, ore deposition, magmatism, and orogeny, 871
Geological maps, Baja Calif., Mexico, 45
Copper Cities area, Ariz., 364
Day Book dunite deposit, N. C., 212
Guadalupe mine, Nuevo Leon, Mexico, 494
Hafafit area, Egypt, 319
Hicks Dome area, Illinois, 894
Jersey lead-zinc deposit, 522
Katherine-Darwin region, Northern Territory, 829
Nkana concession, Northern Rhodesia, 577
Pascalis Township, Que., 722
Preissac-Lacorne batholith, Que., 512
Radium Hill uranium district, South Australia, 817
Salmo tungsten district, Brit. Columbia, 629
Stirling area, Nova Scotia, 392
Tennessee (review), 544
Wadi Abu Ghalqa, Egypt, 78
White Pine area, Mich., 684, 707
Yugoslavia, 457
Geological tool, The gold pan: A neglected (Mertie), 639
Geologists, R. Rao, autobiography, India (review), 547
Geology, Angaur Island (abstract), 810
Cobalt district, Ont., 378
Coeur d'Alene district, Idaho, 754
Cold Spring tungsten mine, Colo. (abstract), 123
Copper Cities copper deposit, Ariz., 363
copper minerals, White Pine district, Mich., 695
Day Book dunite area, N. C., 213
Dillon graphite district, Mont., 35
Elizabeth copper mine, Vermont, 3, 5
Goudreau area, Ontario, 311
Granite Mtn. area, Utah (review), 795
Guadalupe mine, Nuevo Leon, Mexico, 493
Hafafit anthophyllite-vermiculite deposit, Egypt, 317
historical geology, textbook (review), 103
Houston-Galveston region, Texas, 415
ilmenite deposit, Abu Ghalqa, Egypt, 77
Jersey lead-zinc deposit, B. C., 523
Katherine-Darwin region, Northern Territory, 828
Lac La Ronge district, Saskatchewan, 617
Mindamar mining district, Nova Scotia, 391
O'Brien mining district, Que., 423
Palomas (Hermosa) district, New Mexico, 761
pegmatitic lithium deposits, Canada, 504
Roan Antelope copper belt, Northern Rhodesia, 576
Salmo district, Brit. Columbia, 628
salt and cap rock, Gulf Coast salt domes (abstract), 805

Geology—*Continued*
Tennessee, east Tenn. (review), 544
Yugoslavia, mineralized areas, 455
Geology and ore deposits of Baja California, Mexico (Wisser), 44
Geology as defined and used, Certain terms of mining (Schmitt), 198
Geology of the Radium Hill uranium mine, South Australia (Parkin and Glasson), 815
Geomorphology, textbooks (reviews), 227, 794
Geophysical prospecting, electric well logs, Hicks Dome, Ill., 898
Rum Jungle area, Northern Territory, 834
Geophysics, definition, 202, 203
Georgia, pavements, De Kalb Co., 643
Geosynclines (review), 104
Baja Calif., Mexico, 54
Huronian, Lake Superior region, 279
Germanite, 808
Germanium, South West Africa, Tsumeb deposit, germanite and reniérite (abstract), 808
Germany, coal, thermal curve, 299
Gersdorffite, 159, 753, 756
Gill, J. E., on hematitic rocks, 257
on iron formation, 440
Gilluly, J., on Ajo district, Ariz., 869
on silica, 880
Gilluly, J., and Grant, U. S., on subsidence, 419
Gilsonite, uranium extraction, 654, 656
Glass, H. D., *Investigation of rank in coal by differential thermal analysis*, 294–309
Glasses, silicates (review), 547
Glasson, K. R., with Parkin, L. W., *The geology of the Radium Hill uranium mine, South Australia*, 815
Glauconite, 263
Globe-Miami district, Arizona, Copper Cities copper deposit (Peterson), 362
Goddard, E. N., *et al.*, on rock color, 405
Goethite, 441, 773
Gold, 402, 537, 772
Baja Calif. deposits, Mexico, 68
British Columbia, Sheep Creek district, 524
deposition temperature, 560
enrichment by meteoric waters, 426, 429
Pacific quartz-gold belt, 44, 57
Quebec, 723
Lamaque No. 6 vein, 530
U. S., mining camps of the West (review), 442
Yugoslavia, 454, 461, 470, 475, 478
Gold mine, Kewagama, Quebec, Vertical zoning at the O'Brien (Mills), 423
Gold pan: A neglected geological tool (Mertie), 639
Goldschmidt, V. M., on atomic bonds, 565
on skarn, 633
review of book by, 666
Gold-uranium deposits, Genesis of the Witwatersrand (Miholić), 537
Goranson, R. W., on magma, 865
Gossans, hematite-limonite, Rum Jungle area, Northern Territory, 832
Yugoslavia, 466, 467, 474
Goudreau area of Algoma, Ontario, Pyritic mineralization in the (Douglas), 310
Grabens, 44, 64
Graf, D. L., and Lamar, J. E., abstract by, 809
Granigg, B., on ore deposition, 468
Granite, 436
graphic granite, N. W. T., 506
mapping in southeast U. S., 644
radioactivity, Katherine-Darwin region, Northern Territory, 828
Granitization, 566
oxyphile elements, segregation, 561
Granules and ooliths, 255
Graphite, carbon in iron formations, 251
origin, 542
uranium extraction, 654
Graphite deposits near Dillon, Montana, Occurrence and origin of the (Ford), 31
Graphs—
artesian pressure head declines, Houston, Texas, 416
chemical analyses, rocks, Needle Mtn., Gaspe, Que., 518
coal analyses, Nova Scotia, 838
cobalt content of glacial materials, Ont., 382
gold ratio to all precious metals, O'Brien mine, Que., 425
histograms, Hamp well sand, Ill., 900
mercury sulphides, solubility, 190
radioactivity adjacent to ore contacts, 719
stability fields of iron minerals, 241
sulphide phases formation, 748
uranium extraction by materials, 655
Graton, L. C., on mineralizing fluids, 884
Gray, A., on Roan Antelope copper belt, Northern Rhodesia, 576
Greenalite, 236, 263, 264
Griffith, R. F., abstract by, 119
Grim, R. E., and Rowland, R. A., on differential thermal analysis, 294
Grip, E., and Ödman, O. H., on thucholite, 537
Gross, W. H., on radioactivity, 720, 829
on uranium, 562
Ground water, Angaur Island (abstract), 810
Copper Cities copper deposit, Ariz., 373
Rum Jungle area, Northern Territory, 833

Ground water in the Houston-Galveston region, Texas, Land-surface subsidence and its relation to the withdrawal of (Winslow and Doyel), 413
Grout, F. F., on calcite, 400
on hematitic rocks, 257
Grout, F. F., and Thiel, G. A., on stilpnomelane, 264
Gruner, J. W., on iron, 242, 257
on iron silicates, 263
on uraninite, 351
on vermiculite, 218
Gruner, J. W., and Gardiner, L., on uraninite, 351
Gruner, J. W., Gardiner, L., and Smith, D. K., Jr., on asphaltite, 358
Gruner, J. W., Towle, C. C., and Gardiner, L., on uraninite, 351
Gruner, J. W., with Rosenzweig, A., and Gardiner, L., *Widespread occurrence and character of uraninite in the Triassic and Jurassic of the Colorado Plateau,* 351
Grunerite, 439
Grus or gruss, 641
Guadalupe mine, Nuevo Leon, Mexico, Ore controls at the (Whiting), 493
Guild, P. W., discussion of paper by, 659
Gulf Coast, salt domes, salt and cap rock (abstract), 805
sulphur in salt domes, origin (abstract), 806
Gushkin, G. G., and Prikhidko, P. L., on inclusions, 207
Gussow, W. C., on igneous rocks, 511
Gustafson, J. K., discussion by, 783
Gustafson, J. K., Burrell, H. C., and Garretty, M. D., on minerals, 784
Gypsum, 773

Hacquebard, P. A., on clarodurain, 849
on coal, 843
Hacquebard, P. A., and Lahiri, K. C., *Petrographic examination of washed, screened and crushed samples of coal from the Sydney and St. Rose coalfields, Nova Scotia,* 837–862
Hadley, J. B., on alteration, 219
on limestone, 61
Hafafit, Eastern Desert, Egypt, Anthophyllite-vermiculite deposit of (Amin and Afia), 317
Halite, 805
Hallimond, A. F., on ferrous carbonate, 244
review of book by, 226
Hallimond, A. F., *et al.,* on ooliths, 256
Hanna, G. D., on Cedros Island, Mexico, 49
Harder, E. C., and Johnston, A. W., on iron carbonate rock, 253
Hardin County, Illinois, Explosion pipe in test well on Hicks Dome (Brown, Emery, and Meyer), 891
Harker, A., on metamorphism, 200, 613
on oölitic hematites, 256
on ottrelite schists, 314
Harley, G. T., on Palomas district, New Mexico, 761
Harrel, M. A., and Eckel, E. B., on limestone, 89
Harris, F. R., and Harlow, E. H., on ground water, 419
Hawley, J. E., on pyrite, 248, 408
on sulphur, 28
Haycock, M. H., on ore minerals, 401
Hayes, A. O., on hematite, 256
Heavy minerals, separation by panning, 649
Heinrich, E. W., on pegmatites, 35
Heise, W., on Bor district, Yugoslavia, 473
Helfinstine, R. J., on coal, 303
Helium, 538
Hematite, 67, 83, 236, 249, 256, 262, 272, 285, 292, 773, 832
Hematite quartzites, 240
Henderson, J. F., on Yellowknife-Beaulieu region, N.W.T., 504
Henderson, J. F., and Jolliffe, A. W., on Yellowknife-Beaulieu district, N.W.T., 504
Herb Lake lithium pegmatite district, Man., 510
Herdsman, W. H., analysis by, 394
Hermann, F., on antimony, 479
Hermann, F., and Mempel, G., on lead and zinc, 462
(*Hermosa*) *district, southwestern New Mexico, Paragenesis of the ores of the Palomas* (Jicha), 759
Hess, F. L., on ores, 351
Hess, H. H., on dunite, 213
Hessite, 748
Heverly, J. R., on freezing point, 193
Heyl, A. V., abstract by, 120
Hicks Dome, Hardin County, Illinois, Explosion pipe in test well on (Brown, Emery, and Meyer), 891
Hiessleitner, G., on Janjevo mining district, Yugoslavia, 473
Hillebrand, J. R., *A suggested source of the thiophile elements of the Tertiary ore deposits of the southwest,* 863–876
Hillebrand, W. F., and Schaller, W. T., on kleinite, 179
Hindustan, charnockites (review), 338
hematite quartzites, 240, 276
Kolhan series (discussion), 332
R. Rao, autobiography (review), 547
Hirahara, E., on chalcocite, 749
Hirschi, H., and De Quervain, F., on peridotite, 50
Histograms, copper content of sediments, Mich., 697

Historical geology, textbook (review), 103
History, mining, Iron Mtn., B.C., 626
petrology (review), 913
Radium Hill uranium mine, South Australia, 816
uranium exploration, Northern Territory, 827
Vermont copper belt, 2
Yugoslav mining industry, 453
Hitchcock, E., *et al.*, on copper, 2
Hobbs, S. W., Wallace, R. E., and Griggs, A. B., on bleaching, 754
Hoffmann, H., and Kühlwein, F. L., on coke, 842
Holland, H. D., and Kulp, J. L., on scintillation technique, 149
Holland, H. D., with Koehler, G. F., and Hostetler, P. B., *Geochemical prospecting at Cobalt, Ontario*, 378
Hollings, H., and Cobb, J. W., on coal, 294
Holmes, A., on a time scale, 793
on the Jurassic, 59
Holmes, R. J., on minerals, 379
Hornblende, 11, 23
Hornstone, 201, 203
Hostetler, P. B., with Koehler, G. F., and Holland, H. D., *Geochemical prospecting at Cobalt, Ontario*, 378
Hotchkiss, W. O., on slate, 248
Houston-Galveston region, Texas, Land-surface subsidence and its relation to the withdrawal of ground water in the (Winslow and Doyel), 413
Howe, H. M., on copper, 2
Hubbert, M. K., on ground water, 182
Human relationships in future mineral procurement (Davidson), 345; discussion, 906
Hume, W. F., on granite, 77
on Hafafit Range, Egypt, 317
Hunter, C. E., on olivine, 211
Hunter, C. E., Murdock, T. G., and MacCarthy, G. R., on chromite, 211
Hurley, P. M., abstract by, 802
Hutchins, J. P., on chromite, 49
Hutchinson, M. W., with Fryklund, V. C., Jr., *The occurrence of cobalt and nickel in the Silver Summit mine, Coeur d'Alene district, Idaho*, 753
Hutchinson, R. D., on Mindamar mining district, Nova Scotia, 391
Hutton, C. O., on stilpnomelane, 264
Hydrargillite (gibbsite), 488
Hydrobiotite, 809
Hydrocarbonic solutions, 209
Hydrophilic series of metals, 152
Hydrosaline solutions, 207
Hydrosilicate solution, 209
Hydrothermal, definition, 202, 203
Hypogene ore deposits, The origin of the silica of the bedrock (Schmitt), 877
Idaho, The occurrence of cobalt and nickel in the Silver Summit mine, Coeur d'Alene district (Fryklund and Hutchinson), 753
Idria mercury deposit, Yugoslavia, 479
Igneous rocks, aphanites for lightweight aggregate (communication), 435
bloating tests, 435
Lac La Ronge district, Saskatchewan, 617
mercury content, 181
Mindamar mining district, Nova Scotia, 392
Preissac-Lacorne lithium district, Que., 511
textbook (review), 337
Illinois, Explosion pipe in test well on Hicks Dome, Hardin County (Brown, Emery, and Meyer), 891
coal, thermal curves, 301, 305
lead-zinc district, structure (abstract), 120
Illite, 192
Ilmenite, 404, 641, 822
Ilmenite deposit of Abu Ghalqa, Egypt (Amin), 77
Imlay, R. W., on a seaway, 54
Inclusion data, Composition of vein-forming fluids from (Smith), 205
Inclusions, liquid inclusions, 331, 728, 730
leakage or filling (discussion), 786
quartz vein, Lamaque, Que., 530
sulphides, 596
Indium, melting point and occurrence, 562
Indonesia, mountain building (review), 664
Ingerson, E., *Nature of the ore-forming fluids at various stages—A suggested approach*, 727–733
on isotopes, 541
Ingerson, E., with Richter, D. H., discussion by, 786
Ingham, W. N., and Keevil, N. B., on radioactivity, 720
Intergrowths, chalcopyrite-bornite, 595
exsolution intergrowths, ilmenite and hematite, Egypt, 83, 86
Intrusive effects of dikes in sulfide ores, 405
Intrusives, determination of ore occurrence possibilities, 731
Inversion temperatures of Cu_2S and CuS, 735
Ionium, 899
Iron, bacterial formation, 538
Baja Calif. deposits, Mexico, 67
Brazil, Congonhas district (discussion), 659
France, Lorraine basin (review), 441
iron formation, sedimentary facies (discussion), 905
magnetite-hematite deposits, Calif.—Baja Calif., 61

Iron—*Continued*
Michigan, origin of soft ores (discussion), 439
Minnesota, Soudan deposit, replacement and alteration (abstract), 124
Utah, Granite Mtn. area, map (review), 795
Iron Springs deposit, origin, 731
Yugoslavia, 454, 484
Iron-formation, Sedimentary facies of (James), 235
Irving, R. D., on copper, 677
Irving, R. D., and Van Hise, C. R., on iron formation, 253
on soapstone, 440
Isachsen, Y. W., abstract by, 804
Isotopes, nonradiogenic isotopes (discussion), 541
Itabirite, 240

Jackson, G. C. A., on chalcopyrite, 595
Jacobs, E. C., on sillimanite, 5
Jacobs, E. C., and Doll, C. G., on copper, 2
Jacobsite, 68
Jahns, R. H., on mineralization, 777
review of bulletin by, 335
James, H. L., *Sedimentary facies of iron-formation*, 235–293; discussions, 439, 905
on iron, 237
James, H. L., and Dutton, C. E., on slate, 248
James, H. L., and Wier, K. L., on black slate, 248
James, H. L., Clark, L. D., and Smith, L. E., on pyritic slate, 248
Jamison, J. K., on native silver, 696
Janjevo lead-zinc deposit, Yugoslavia, 473
Japan, coal, differential thermal analysis, 295
Jarrard, L. D., with Thurlow, E. E., abstract by, 125
Jasperoid, 201, 203
Jaspilite, 258
Jenkner, A., on coke, 842
Jennings, E. P., on gabbro, 131
Jenny, H., *et al.*, on pH measurement, 192
Jensen, M. L., discussion of paper by, 541
Jersey lead-zinc deposit, Salmo, B. C. (Whishaw), 521
Jicha, H. L., Jr., *Paragenesis of the ores of the Palomas (Hermosa) district, southwestern New Mexico*, 759–778
on ore bodies, 468
Johnston, W. D., Jr., on intrusives, 59
Johnstone, S. J., review of book by, 913
Joints, Cobalt district, Ont., 379
copper deposits, White Pine, Mich., 708
porphyry copper deposits, western U.S. (abstract), 122
Preissac-Lacorne batholith, Que., 513
Roan Antelope copper belt, Northern Rhodesia, 583, 585
Joints—*Continued*
Upper Miss. Valley zinc-lead district (abstract), 120
Jolliffe, A. W., on Yellowknife-Beaulieu district, N.W.T., 504
Jolliffe, F. J., on greenalite, 264
Jones, F. A., on miargyrite, 771
Jost, W., on diffusion, 741
Jugoslavia and the development of its mining industry, The ore deposits of (Schumacher), 451
Jurassic, paleogeography, Baja Calif., Mexico, 51
Jurassic sediments of the Colorado Plateau, Widespread occurrence and character of uraninite in the Triassic and (Rosenzweig, Gruner, and Gardiner), 351
Just, E., discussion by, 906

Kämmererite, 484
Kaolin, decomposition by diatoms, 538
Kaolinite, 130, 135, 440, 773, 776
Karsts, Yugoslavia, bauxite deposits, 487
Katz, J. J., and Rabinowitch, E., on uranium, 169, 355, 653
Katzer, F., on iron ore, 484
on ore deposits, Yugoslavia, 455
Keith, A., on talc, 775
Kelley, V. C., on chert, 274
Kemp, J. F., on hornstone, 201
Kennedy, G. C., on inclusions, 206, 786
Kerr, P. F., on tungsten, 60, 637
Kerr, P. F., and Kulp, J. L., on uranium, 754
Kerr, P. F., and Robinson, R. F., on Silver Belt, Idaho, 754
Kerr, P. F., *et al.*, on alteration, 146
Kidd, D. F., and Haycock, M. H., on uraninite, 154
Kidwell, A. L., on diatremes, 896
King, C., on granite, 221
King, H. F., and O'Driscoll, E. S., discussion of paper by, 783
King, H. F., and Thomson, B. P., discussion of paper by, 783
King, P. B., on ultramafic bodies, 211
King, R. E., on volcanics, 54
King, R. U., on uraninite, 131
King, R. U., with Vanderwilt, J. W., abstract by, 125
Kinkel, A. R., Jr., abstract by, 120
Kirk, M. V., and MacIntyre, J. R., on Alisitos formation, Mexico, 48
Kitazaki, U., and Yagishita, H., on coal, 295
Klaprotholite, 750
Kleinite, 178
Knife blade manganese ore, Ariz., 89
Knight, C. W., on Cobalt district, Ont., 378
Knopf, A., on a time scale, 793
on ankeritization, 879
Knox, J., on mercury, 188

Kober, L., on serpentine, 482
Koehler, G. F., Hostetler, P. B., and Holland, H. D., *Geochemical prospecting at Cobalt, Ontario,* 378–388
Kolthoff, I. M., on solutions, 194
Kopaonik lead-zinc deposit, Yugoslavia, 465
Kossmat, F., on ore deposits, Jugoslavia, 455
Krauskopf, K. B., on gold, 429
on mercury, 176
Krotov, B. P., on magnetite, 258
Krumbein, W. C., and Garrels, R. M., on sediments, 240
Krynine, P. D., on tourmaline, 604
Kühlwein, F. L., on coke, 842
Kühlwein, F. L., and Abramski, C., on coal, 842
Kulp, J. L., and Brobst, D. A., *Notes on the dunite and the geochemistry of vermiculite at the Day Book dunite deposit, Yancey County, North Carolina,* 211-220
Kulp, J. L., Bate, G. L., and Broecker, W. S., on age determinations, 793
Kulp, J. L., Kent, P., and Kerr, P. F., on carbonate minerals, 255
Kushida, T., on cuprous sulphide, 747

Lac La Ronge district, northern Saskatchewan, Radioactive, pronouncedly differentiated pegmatite sill (Mawdsley), 616
Lacroix, A., on alkalies, 231
on lherzolite, 731
Lahiri, K. C., with Hacquebard, P. A., *Petrographic examination of washed, screened and crushed samples of coal from the Sydney and St. Rose coalfields, Nova Scotia,* 837
Lake Superior region, iron formation, sedimentary facies, 235
Lakes, Minnesota (review), 795
Lakin, H. W., Almond, H., and Ward, F. W., on tests for cobalt, 383
Lamaque No. 6 vein, Direction of flow of late stage solutions in the (Smith), 530
Lamey, C. A., on limestone, 61
Land bridges (review), 106
Landergren, S., on iron ores, 244
Land-surface subsidence and its relation to the withdrawal of ground water in the Houston-Galveston region, Texas (Winslow and Doyel), 413
Lane, A. C., and Seaman, A. E., on Nonesuch shale, Mich., 680
Lang, A. H., on Coast Range batholith, B. C., 61
on uranium, 563
Lang, J. W., and Winslow, A. G., on Houston-Galveston region, Texas, 415
Langford, G. B., review of book by, 547
Larsen, E. S., Jr., on Baja Calif. batholith, Mexico, 47
on corundum, 218
on magmas, 732
Larsen, E. S., Jr., and Berman, H., on olivine, 217
Lasky, S. G., on Central district New Mexico, 869
Laterite, French Guinea, Conakry iron deposit (discussion), 905
nickel-cobalt ore, Cuba (abstract), 117
Northern Ireland, Antrim (review), 108
Rum Jungle area, Northern Territory, 832
Latimer, W. M., and Hildebrand, J. H., on uranyl sulphate, 653
Latsky, R., on bornite, 596
Lawson, A. C., on Great Valley, Calif., 58
Lazarevic, M., on Bor district, Yugoslavia, 473
Le Chatelier principle, 193
Leaching, silver from gold alloy, 429
Lead, melting point and zoning, 557
New South Wales, Broken Hill deposit (discussion), 783
Sierra Nevada batholith, Calif., 58
transportation and deposition, 728
Upper Miss. Valley structure (abstract), 120
Washington, Metaline district (abstract), 121
Yugoslavia, 454, 460
Lead-copper deposits at the Mindamar mine, Nova Scotia, Paragenesis of the zinc (Watson), 389
Lead-zinc deposit, Salmo, B. C., The Jersey (Whishaw), 521
LeBourdais, D. M., review of book by, 442
Leighton, F. B., abstract by, 809
Leith, C. K., on greenalite, 263
on hematite rock, 259
Leith, C. K., and Mead, W. J., on magnetite, 101
Leopard (chromite) ore, 482
Lepidocrocite, 773
Lepidolite, 504, 508
South West Africa, pegmatite deposits (abstract), 117
Lesure, F. G., books received, 109, 227, 340, 444, 548, 666
review by, 546
Levin, S. B., Nye, W. F., and Kedesdy, H., abstract by, 807
Leze lead-zinc deposit, Yugoslavia, 470
Lievrite, 463
Life, origin, migration, and formation of sediments (review), 103
Lignite, A method for the petrographic analysis of commercially delivered (Traverse), 92
uranium extraction, 654
Yugoslavia, 454
Lime, loss during alteration, Gaspe, Que., 519

Limonite, 484, 772
Lind, S. C., on methane, 537
Lindgren, W., on gel metasomatism, 162
on metamorphism, 200
on Roan Antelope ores, Northern Rhodesia, 609
on schists, 50
on silica, 880
on solubility, 556
Lindgren, W., Graton, L. C., and Gordon, C. H., on enrichment, 775
Lithium deposits in Canada, Pegmatitic (Rowe), 501
Little, H. W., on Salmo area, B. C., 628
Little, R., photos by, 10, 14
Ljubija iron ore district, Yugoslavia, 484
Ljuboten chromite district, Yugoslavia, 482
Lodochnikov, V. N., on minerals, 732
Loewinson-Lessing, F. J., review of translation of a book by, 913
Lojane chromite district, Yugoslavia, 483
Love, J. D., on uranium, 652
Lovering, T. S., on alteration, 754
on Caribou intrusives, Colo., 131
on ores, 867
on silica, 883
Lovering, T. S., and Goddard, E. N., on Front Range mineral belt, Colo., 866
on intrusives, 131
Luminescence of certain intrusive rocks and hydrothermal ore deposits, The marginal (McDougall), 717
Lutjen, G. P., and Kearney, J. H., on copper, 3

McDougall, D. J., *The marginal luminescence of certain intrusive rocks and hydrothermal ore deposits*, 717–726
on fluorescence, 719
MacGregor, A. M., on atmosphere, 245
Mackay, R. A., on gold, 429
on ions, 152
McKelvey, V. E., and Nelson, J. M., on uranium, 652
Mackin, J. H., on iron, 731
review of map by, 795
McKinstry, H. E., on terms, 198
McKinstry, H. E., and Mikkola, A. K., *The Elizabeth copper mine, Vermont*, 1–30
Magmas, ore-forming fluids, 727
Magmatization, ore deposits and blister heat (abstract), 810
Magnesite, 395
calcination (abstract), 809
Yugoslavia, 454, 489
Magnetite, 67, 236, 247, 257, 261, 270, 273, 285, 292, 441, 622, 641, 731
origin (communication), 101
Magnets for mineral separation, 650
Majdan Pek copper deposit, Yugoslavia, 476
Malachite, 772
Man (review), 107
Manganese, activator of carbonate minerals, 718, 721
bacterial formation, 538
Baja Calif., Mexico, 44, 66, 68, 72
gold enrichment by manganese dioxide, 429
Yugoslavia, 454, 486
Manganese deposits of the Mogollon Rim, Coconino County, Arizona (Silver), 88
Manganese dioxide for dry cells (abstract), 807
Manitoba, Birch Lake, schist, 724
lithium pegmatite deposits, 507
Mann, V. I., discussion by, 439
Mapping, North Carolina, gold pan technique, 643
Rum Jungle area, Northern Territory, 833
Mapping from aerial photos (communication), 780
Maps, Agaunico mine area, Cobalt, Ont., 380
Australia, Radium Hill uranium district, 816
British Columbia, Salmo area, 521
Canada, lithium pegmatite deposits, 502
Egypt, Hafafit area, 318
iron formations, Lake Superior region, 238
Jahala or Lee Lake, Saskatchewan, 618
Montana, Crystal graphite mine, 32
New Mexico, Sierra County, 760
paleogeographic maps, Jurassic, Baja Calif., Mexico, 51
piezometric map, Houston-Galveston region, Texas, 417
Salmo district, Brit. Columbia, 626
Stirling area, Nova Scotia, 390
uplifts and basin-and-range faults, western North America, 62
uraninite occurrences, Colo. Plateau, 352
uranium occurrences in Australia, 827
Utah, Granite Mtn. area (review), 795
Vermont, copper belt, 3
White Pine area, Mich., 678
Marble, Dillon area, Mont., 37
Martite, 247
Mason, B., on metals, 864
Mawdsley, J. B., *Radioactive, pronouncedly differentiated pegmatite sill, Lac La Ronge district, northern Saskatchewan*, 616–624
on diabase, 408
Mawson, D., on davidite, 822
on Radium Hill mine, South Australia, 816
Mead, W. J., on alteration, 440
Meinzer, O. E., on aquifers, 418

Meinzer, O. E., and Wenzel, L. K., on aquifers, 790
on fine-grained materials, 418
Melcher, A. F., on paraffin coatings, 436
Mellor, E. T., on gravel, 539
Melnikowite, 258
Melting point and ore deposition, Metallic (Sullivan), 555
Mempel, G., on Bor district, Yugoslavia, 473
Mercury, California, Sulphur Bank deposit (abstract), 807
system HgS—Na_2S—H_2O (abstract), 807
Yugoslavia, 479
Mertie, J. B., Jr., *The gold pan: A neglected geological tool*, 639–651
on monazite, 644
Merwin, H. E., and Lombard, R. H., on copper, 737
Mesogene, 202, 203
Metacinnabar, 807
Metallic melting point and ore deposition (Sullivan), 555
Metallization, 202
Yugoslavia, 456
Metallogenetic provinces, Pacific Coast gold-quartz belt, 57
Yugoslavia, 457, 458
Metals, occurrence in rocks, 864
Metamorphism, Broken Hill ore deposit, New South Wales (discussion), 784
contact metamorphism, silica additions and losses, 882
Day Book dunite, N. C., 213
definition, 200, 203
Dillon area, Mont., 37
Guadalupe mine, Mexico, 495
iron formation (discussion), 439
Lake Superior region, 238
ottrelite schists, 314
peridotite contact metamorphism, 732
Salmo district, B. C., 524
siltstone, Mindamar area, Nova Scotia, 393, 394
textbook (review), 337
Vermont copper district, 5
Metasomatism, 200, 203
Metastibnite, 740
Metatorbernite, 368
Meteorite, composition, 888
Methane, Witwatersrand and Boliden mines, 537
Method for the petrographic analysis of commercially delivered lignite (Traverse), 92
Mexico, Geology and ore deposits of Baja California (Wisser), 44
Ore controls at the Guadalupe mine, Nuevo Leon (Whiting), 493
Meyer, P. A., Jr., with Brown, J. S., and Emery, J. A., *Explosion pipe in test well on Hicks Dome, Hardin County, Illinois*, 891
Mežica (Miess) lead-zinc deposit, Yugoslavia, 468
Michigan, The White Pine copper deposit, Ontonagon County (White and Wright), 675
copper, arsenic and native copper (communication), 908
iron, origin of soft ores (discussion), 439
iron formations, sedimentary facies, 235
Micrinite, 850
Microbiology, petroleum (review), 912
Microcline, 508, 723
Microscopy, polarization microscope, optics (reviews), 224, 226
Miholić, S., *Genesis of the Witwatersrand gold-uranium deposits*, 537–540
on water, 538
Mikkola, A. K., with McKinstry, H. E., *The Elizabeth copper mine, Vermont*, 1
Miles, K. R., on iron formation, 257
Miller, G. J., Parkins, A. E., and Hudgins, B., review of book by, 665
Miller, R. E., review by, 544
Miller, W. G., on Cobalt district, Ont., 378
Mills, H. F., abstract by, 121
Mills, J. W., *Vertical zoning at the O'Brien gold mine, Kewagama, Quebec*, 423–430
on O'Brien mine, Que., 423
Milner, H. B., on apatite, 604
Mimetite, 772
Mindamar mine, Nova Scotia, Paragenesis of the zinc-lead-copper deposits at the (Watson), 389
Mine, South Australia, The geology of the Radium Hill uranium (Parkin and Glasson), 815
Mineral deposit, defined, 201, 203
Mineral deposits and rocks (review), 545
Mineral industry, Canada (review), 547
consumption requirements and exploration data (editorial), 432
tin (review), 226
Yugoslavia, 454
Mineral procurement, Human relationships in future (Davidson), 345
Mineral resources (review), 339
exploration data needed (editorial), 433
lithium pegmatites, Canada, 514
Mineralization, Climax molybdenite deposit, Colo. (abstract), 125
copper, Arizona, Copper Cities deposit, 362, 369
Globe-Miami district (abstract), 122
Silver Bell area (abstract), 123

Mineralization—*Continued*
Roan Antelope deposit, Northern Rhodesia, 580, 607, 609
White Pine district, Mich., 708
copper-zinc California, Shasta district (abstract), 120
defined, 201, 203
fluids, composition, 884
gold, Lamaque mine, Que., 536
Guadalupe mine, Mexico, 493, 496
Hicks Dome, Illinois, 897
iron, Granite Mtn. area, Utah (review), 796
lead-zinc, Washington, Metaline district (abstract), 121
Little Cottonwood stock, Utah (communication), 222
mercury, Terlingua, Texas, 175
Nevadan—Baja Calif. orogenies, 44, 57
Palomas mining district, New Mexico, 759, 776
Radium Hill mine, South Australia, 821, 822
tungsten, Salmo district, B. C., 625
Yugoslavia, 456
zinc, Tennessee, Friends Station—New Market area (abstract), 121
Mineralization in the Goudreau area of Algoma, Ontario, Pyritic (Douglas), 310
Mineralogy, carbonate mineralogy of carbonate rocks (abstract), 809
Climax molybdenite deposit, Colo. (abstract), 125
determinative tables (review), 337
germanite and reniérite, Tsumeb, South West Africa (abstract), 808
iron formations, 239, 249
lithium pegmatites, Canada, 503
metasomes in wall-rock alteration, 882
ores, cobalt-nickel, Cobalt, Ont., 379
Copper Cities copper deposit, Ariz., 367
El Triunfo-San Antonio district, Mexico, 71
Jersey lead-zinc deposit, B. C., 526
Mindamar mine, Nova Scotia, 389, 390
Palomas district, N. Mexico, 759, 765
Roan Antelope copper deposit, Northern Rhodesia, 591
Trepča lead-zinc deposit, Yugoslavia, 463
uraninite, Colo. Plateau, 356
pegmatites, Arizona, White Picacho district (review), 336
Perron mine, Que., 723
Radium Hill uranium mine, South Australia, 815
salt and cap rock of salt domes, Gulf Coast (abstract), 805
Silver Summit tetrahedrite veins, Idaho, 755
textbook (review), 225
Mineralogy of a uraninite deposit at Caribou, Colorado (Wright), 129
Minerals, alteration minerals, Caribou, Colo., 135
atomic energy minerals (review), 912
chemical industry needs (review), 913
determinative tables (review), 337
field guide (review), 225
metasomes in wall-rock alteration, 882
Minnesota (review), 795
polarity rule, 732
Mining, Canadian industry (review), 547
Iron Mtn. district, B. C., 626
phosphate rock, Angaur Island (abstract), 810
Roan Antelope copper deposit, Northern Rhodesia, 583
Mining geology as defined and used, Certain terms of (Schmitt), 198
Mining industry, The ore deposits of Jugoslavia and the development of its (Schumacher), 451
Minnesota, iron, Soudan deposit, replacement and alteration (abstract), 124
iron formations, sedimentary facies, 235
rocks and waters (review), 795
Minnesotaite, 236, 249, 254, 262, 265, 285, 293, 439
Missouri, diatremes, southeast Mo., 896
lead deposits, genesis, 571
Mitcham, T. W., on Silver Belt, Idaho, 754
Moehlman, R. S., on gold, 68
Mogollon Rim, Coconino County, Arizona, Manganese deposits of the (Silver), 88
Molybdenite, 27, 125, 222, 362, 367, 368, 635
Yugoslavia, 454, 480
Molybdenum, occurrence, 563
Monazite, 509, 616, 622, 642, 644, 648, 650
exploration techniques (abstract), 119
Montana, Occurrence and origin of the graphite deposits near Dillon, (Ford), 31
uranium deposits, Boulder batholith (abstracts), 125, 803
Montebrasite, 501, 504
Montmorillonite, 130, 135
Montroseite, 804
Montroydite, 179
Moore, E. S., on pyrite, 248, 316
Moore, E. S., and Armstrong, H. S., on pyrite-siderite, 248
Moore, E. S., and Maynard, J. E., on iron, 242
Moore, G. W., *Extraction of uranium from aqueous solution by coal and some other materials,* 652-658
Moore, R., review of book by, 107
Moorehouse, W. W., on sulphides, 865
Mosesite, 178
Mott, N. F., and Gurney, R. W., on luminescence, 719
Mott, R. A., and Wheeler, R. V., on plasticity, 296

Mountain, E. D., on sericite, 602
Mountain building (review), 664
Muds, black muds, uranium content, 538
Muir, A., review of book edited by, 666
Murdock, T. G., and Hunter, C. E., on vermiculite, 211
Murray-Hughes, R., on Janjevo mining district, Yugoslavia, 473
Muscovite, 222
  Arizona, pegmatite belt (review), 336
Mylonitization, sulphides, Nova Scotia, 409

Nanz, R. H., Jr., on iron, 245
Native copper, 695, 808
Native copper and arsenic (communication), 908
Native silver, 161, 696, 764, 771
Naumannite, 748
Nelson, E. W., on Boleo copper deposit, Baja Calif., Mexico, 73
Nevada, Ely district, rock alteration, 879
  Steamboat springs, alteration (abstract), 806
  vermiculite, origin, Southern Virgin Mtns. (abstract), 809
New England, pegmatite investigations (review), 792
New Guinea, gold, fineness changes, 426, 430
New Mexico, Paragenesis of the ores of the Palomas (Hermosa) district, southwestern (Jicha), 759
  rocks, alteration, 878
  structure, Santa Rita intrusive (abstract), 122
  uraninite, Grants deposit, 351
New South Wales, copper, Cobar deposit, 561
New Zealand, Wairakei hot springs, alteration (abstract), 806
Newhouse, W. H., on banding, 409
  on brines, 885
  on inclusions, 181
  on ore, 184
Newhouse, W. H., and Flaherty, G. F., on layering, 409
Nickel, lateritic ores, Cuba (abstract), 117
  melting point and occurrence, Sudbury, Ont., 572
  Ontario, Sudbury basin (review), 442
Nickel in the Silver Summit mine, Coeur d'Alene district, Idaho, The occurrence of cobalt and (Fryklund and Hutchinson), 753
Niggli, P., on tourmaline, 605
  review of translated book by, 545
Nikitin, V., and Duhovnik, J., on Trepča area, Yugoslavia, 462
Nininger, R. D., review of book by, 912
Nishio, K., on copper, 677
Nitschia palea and kaolin formation, 538
Noakes, L. C., on Katherine-Darwin region, Northern Territory, 828
Noble, J. A., on plugs, 63
Nolan, T. B., on exploration, 328
Norman, G. W. H., on igneous rocks, 511
North America, geography (review), 665
North Carolina, Notes on the dunite and the geochemistry of vermiculite at the Day Book dunite deposit, Yancey County (Kulp and Brobst), 211
  pavements, Mt. Airy, 643
North Dakota, lignite, petrography, 93
North West Territories, Yellowknife-Beaulieu district, 504
Northern Ireland, bauxites and laterites (review), 108
Northern Rhodesia, The origin of the Roan Antelope copper deposit of (Davis), 575
  cobalt-copper deposits, genesis, 569
  copper-cobalt-uranium belt (discussion), 904
Northern Territory, Australia, Uranium exploration by the Bureau of Mineral Resources, Geology and Geophysics in the Rum Jungle province (Fisher and Sullivan), 826
Norway, black mud deposition in fjords, 539
  carbonates, Fen district, 316
Nova Scotia, Paragenesis of the zinc-lead-copper deposits at the Mindamar mine (Watson), 389
  Petrographic examination of washed, screened and crushed samples of coal from the Sydney and St. Rose coalfields (Hacquebard and Lahiri), 837
Novo Brdo lead-zinc deposit, Yugoslavia, 466
Nowicki, A. L., on control points, 780
Nuevo Leon, Mexico, Ore controls at the Guadalupe mine (Whiting), 493

O'Brien gold mine, Kewagama, Quebec, Vertical zoning at the (Mills), 423
Occurrence and character of uraninite in the Triassic and Jurassic sediments of the Colorado Plateau, Widespread (Rosenzweig, Gruner, and Gardiner), 351
Occurrence and origin of the graphite deposits near Dillon, Montana (Ford), 31
Occurrence of cobalt and nickel in the Silver Summit mine, Coeur d'Alene district, Idaho (Fryklund and Hutchinson), 753
Oceania, Angaur Islands, salt-water encroachment (abstract), 810
Oceans, chemical environment, 240
Oder, C. R. L., abstract by, 121
Ohio, magnetite in Maxville limestone (communication), 101

Oil shale, uranium extraction, 654
Olivine, 217
Ontario, Geochemical prospecting at Cobalt (Koehler, Hostetler, and Holland), 378
Pyritic mineralization in the Goudreau area of Algoma (Douglas), 310
Dome stock, radioactivity distribution, Red Lake, 719
pyrite-siderite, Michipicoten district, 248
Sudbury basin (review), 442
Sudbury nickel-copper deposits, genesis, 572
Ontonagon County, Michigan, The White Pine copper deposit (White and Wright), 675
Oolites, 255, 259, 272, 275, 285, 292
Minette iron ores, Lorraine basin, France (review), 441
Ooliths and granules, 255
Oosterbosch, R., and Schuiling, H., on ores, 569
Opal, 807
cinnabar in opal, 195
Opaque matter in coal, 855
Ordonez, G., and Baltosser, W. W., abstract by, 122
Ore at Gaspe copper mines, Alteration associated with (Bell and Scott), 516
Ore bodies, Salmo, British Columbia, The Emerald, Feeney and Dodger tungsten (Ball), 625
copper, Copper Cities deposit, Ariz., 362, 376
copper-lead-zinc, Mindamar, Nova Scotia, 389, 390
copper-zinc, California, Shasta district (abstract), 120
El Triunfo-San Antonio district, Baja Calif., Mexico, 70
lead-zinc pipes, Mežica, Yugoslavia, 468
sulphides, Elizabeth copper mine, Vt., 1, 18
tungsten, Colorado, Cold Spring mine (abstract), 124
uranium, Radium Hill mine, South Australia, 823
zinc, Tennessee, Friends Station—New Market area (abstract), 121
Ore bodies and intrusives, 872, 875
Ore controls at the Guadalupe mine, Nuevo Leon, Mexico (Whiting), 493
Ore deposition, Metallic melting point and (Sullivan), 555
Ore deposits, The marginal luminescence of certain intrusive rocks and hydrothermal (McDougall), 717
The origin of the silica of the bedrock hypogene (Schmitt), 877
anticlinal ore accumulation, 183
Arizona, Globe-Miami district (abstract), 122
Ore deposits—Continued
blister hypothesis and origin of ore deposits (abstract), 810
iron, France, Lorraine basin (review), 441
manganese, Mogollon Rim, Ariz., 88
native copper deposits (abstract), 808
Ontario, Sudbury basin (review), 442
uraninite, Colo. Plateau, 351
uranium, origin (abstract), 118
Rum Jungle area, Northern Territory, 831
uranium-vanadium, Colo. Plateau, estimation of reserves (abstract), 805
Ore deposits of Baja California, Mexico, Geology and (Wisser), 44
Ore deposits of Jugoslavia and the development of its mining industry (Schumacher), 451
Ore deposits of the southwest, A suggested source of the thiophile elements of the Tertiary (Hillebrand), 863
Ore shoots, Elizabeth copper mine, Vt., 4
Guadalupe mine, Mexico, 493, 498
lead-zinc, Leze district, Yugoslavia, 470
Silver Summit mine, Idaho, 755
Ore-forming fluids at various stages—A suggested approach, Nature of the (Ingerson), 727
Ores, cobalt-nickel, Cobalt, Ont., 379
ilmenite, Abu Ghalqa, Egypt, 77
intrusive effects of dikes, 405
lateritic nickel-cobalt, Cuba (abstract), 117
lead-zinc, Jersey deposit, B. C., 521, 526
uranium, Radium Hill mine, South Australia, 815, 822
Rum Jungle area, Northern Territory, 826, 831
zinc-lead-copper, Mindamar mine, Nova Scotia, 389, 405, 411
Ores in the Terlingua district, Texas, Transportation and deposition of quicksilver (Thompson), 175
Ores of the Palomas (Hermosa) district, southwestern New Mexico, Paragenesis of the (Jicha), 759
Organisms and concentration of uranium, 538
Origin, amphibolite, Elizabeth mine, Vt., 12
anthophyllite and vermiculite, Hafafit, Egypt, 326
blister hypothesis and ore deposits (abstract), 810
Broken Hill ore deposit, New South Wales (discussion), 784
charnockites (review), 338
coal fields, Great Britain (review), 665
copper, Boleo deposit, Mexico, 44, 73
porphyry deposits, western U. S. (abstract), 122
White Pine, Mich., 676, 712
corundum, 218

Origin—*Continued*
gold-silver ores El Triunfo-San Antonio, Mexico, 71
iron, Brazil, Congonhas district (discussion), 659
France, Lorraine basin (review), 441
Granite Mtn. area, Utah (review), 796
Iron Springs, Utah, 731
Michigan, soft ores (discussion), 439
Vareš district, Yugoslavia, 486
laterites and bauxites, Northern Ireland (review), 108
lead-zinc ore, Jersey deposit, B. C., 528
magnetite (communication), 101
native copper deposits (abstract), 808
ores, Palomas district, New Mexico, 776
pegmatites, Arizona, White Picacho district (review), 336
pyritic mineralization, Goudreau, Ont., 310, 316
sulphur in salt domes (abstract), 806
tungsten, Salmo district, B. C., 625, 637
uraninite, Lac La Ronge district, Saskatchewan, 623
uranium deposits (abstract), 118
vermiculite, Nevada, Southern Virgin Mtns. (abstract), 809
Origin of the graphite deposits near Dillon, Montana, Occurrence and (Ford), 31
Origin of the Roan Antelope copper deposit of Northern Rhodesia (Davis), 575
Origin of the silica of the bedrock hypogene ore deposits (Schmitt), 877
Orogenies (review), 664
Baja Calif.—Nevadan orogenies, 44, 56
metamorphism, and magmatism, 871
Orthoclase, 137
Ottrelite, 314
Oxidation, Bor copper deposit, Yugoslavia, 474
hydrothermal oxidation of iron ore, Mich. (discussion), 440
ores, Palomas district, New Mexico, 765
Roan Antelope copper deposit, Northern Rhodesia, 598
Oxyphile ores and melting point, 561

Pabst, A., on quartz, 400
Pacific Northwest (review), 794
Paige, S., on alteration, 880
Palache, C., Berman, H., and Frondel, C., on carbonates, 395
on uraninite, 166
Paleogeography, Jurassic, Baja Calif., Mexico, 51
Nonesuch shale, Mich., 685
Palingenesis, concentration of crustal material, 864
Palmqvist, S., on iron ores, 244
Palomas (Hermosa) district, southwestern New Mexico, Paragenesis of the ores of the (Jicha), 759
Pan: A neglected geological tool, The gold (Mertie), 639
Paragenesis, alteration types, Caribou, Colo., 130, 140
germanite and reniérite, South West Africa (abstract), 808
gold-uranium, Witwatersrand, Transvaal, 539
ores, Alamo gold deposit, Baja Calif., Mexico, 69
copper-uranium, Colo. Plateau, 351, 356
Elizabeth copper mine, Vt., 21
Mežica, Yugoslavia, 468
Mindamar mine, Nova Scotia, 405, 411
Roan Antelope copper deposit, Northern Rhodesia, 601
uraninite, Colo., 156, 161, 168
vein minerals and quartz, 884
Paragenesis of the ores of the Palomas (Hermosa) district, southwestern New Mexico (Jicha), 759
Paragenesis of the zinc-lead-copper deposits at the Mindamar mine, Nova Scotia (Watson), 389
Pardee, J. T., and Larsen, E. S., on vermiculite, 326
Park, C. F., Jr., on cherty sediments, 277
Parker, J. M., on dunite, 213
Parker, R. L., review of translation by, 545
Parkin, L. W., and Glasson, K. R., *The geology of the Radium Hill uranium mine, South Australia*, 815–825
Parks, B. C., and O'Donnell, H. J., on lignite, 93
Pauling, L., review of book by, 107
Pavements, 643
Pavlović, S., on Bor district, Yugoslavia, 473
Pearls and gems (review), 663
Peat, uranium extraction, 654
water and temperature ranges, 307
Peele, R., and Church, J. A., on the gold pan, 645
Pegmatite sill, Lac La Ronge district, northern Saskatchewan, Radioactive, pronouncedly differentiated (Mawdsley), 616
Pegmatites, Arizona, White Picacho district (review), 335
Day Book dunite mass, N. C., 214, 216
exterior, interior, and marginal pegmatites, 507
graphite deposits, Mont., 34, 35, 37
hydrosilicate solution, 209
New England (review), 792
oxyphile elements, occurrence, 563
Radium Hill, South Australia, 818
South West Africa (abstract), 117
Pegmatitic lithium deposits in Canada (Rowe), 501
Penck, W., review of translated book by, 227

Pennebaker, E. N., abstract by, 122
Penninite, 136, 404
Pennsylvania, anthracites, thermal curves, 297
Peoples, J. W., review by, 792
Percival, F. G., discussion by, 905
on iron formation, 276
Petalite, 504
Peters, E. D., on copper, 2
Petersen, V. E., on lead-silver sulphide, 768
Peterson, N. P., *Copper Cities copper deposit, Globe-Miami district, Arizona*, 362–377
abstract by, 122
on silica, 880
Peterson, N. P., Gilbert, C. M., and Quick, G. L., on quartz monzonite, 363
Petković, K. V., on a geological map, Yugoslavia, 455
Petrographic analysis of commercially delivered lignite, A method for the (Traverse), 92
Petrographic examination of washed, screened and crushed samples of coal from the Sydney and St. Rose coalfields, Nova Scotia (Hacquebard and Lahiri), 837
Petroleum, microbiology (review), 912
sulphur production from anhydrite (abstract), 806
Texas, oil fields, land subsidence, 420
Petroleum in inclusions, 209
Petrology, charnockites (review), 338
historical survey (review), 913
polarization microscope, optics (reviews), 224, 226
saprolite, correlation with parent bed rock, 642
textbook (review), 337
Pettijohn, F. J., on graywacke, 245
on slate, 248
Phair, G., on uranium, 731
Philipsborn, H. v., review of book by, 337
Phillips, F. C., on anthophyllite, 326
Phlogopite, 12, 217
Phosphate, Anguar Island, mining and salt-water encroachment (abstract), 810
uranium extraction, 654
Photomicrographs—
coal, Nova Scotia, 854
ilmenite and gabbro, Egypt, 82
lignite, N. Dakota, 97
ores, Palomas district, New Mexico, 762, 770
Roan Antelope copper belt, Northern Rhodesia, 597
uraninite, Colo., 153
ores and rocks, Elizabeth copper mine, Vt., 9, 15
Photomicrographs—*Continued*
Mindamar mine, Nova Scotia, 396, 398
rocks, iron formations, 292
serpentine, Egypt, 324
uraninite, Colo. Plateau, 357
Physiography, land forms (reviews), 227, 794
Pichamuthu, C. S., review of book by, 338
Pipe in test well on Hicks Dome, Hardin County, Illinois, Explosion (Brown, Emery, and Meyer), 891
Pipes, 200, 203
breccia pipe, Little Cottonwood stock, Utah (communication), 222
Trepča ore deposit, Yugoslavia, 462, 468
Pitchblende, 125, 162, 539
Placers, gold, Witwatersrand, genesis, 537
Plagioclase, 23, 137
Plans—
anthophyllite-vermiculite deposit, Hafafit, Egypt, 323
Crystal graphite mine, Mont., 33
Guadalupe mine, Mexico, 497
Mindamar mine, Nova Scotia, 403
radioactive sill, Saskatchewan, 621
Radium Hill mine, South Australia, 820
Plants, replacement by copper and uranium, 351, 356
uranium accumulation (abstract), 802
Plaster of Paris for embedding of lignite, 96
Pneumatolytic, definition, 202, 204
Pollock, J. P., on mercury sulphide, 195
Polybasite, 755, 757, 770
Porcellanite, 201, 204
Posnjak, E., Allen, E. T., and Merwin, H. E., on copper, 734
Pough, F. H., review of field guide by, 225
Powellite, 635
Pratt, J. H., and Lewis, J. V., on chromite, 217
Pratt, W. E., discussion by, 790
Pratt, W. E., and Johnson, D. W., on subsidence, 420, 790
Preuss, E., on mercury, 182
Price, P., on ore bodies, 407
Pringsheim, P., on luminescence, 719
Procurement, Human relationships in mineral (Davidson), 345
Propylitization, 200, 371
Prospecting, atomic energy minerals (review), 912
economic data needed (editorial), 433
lateritic nickel-cobalt deposit, Cuba (abstract), 118
monazite (abstract), 119
ore occurrence possibilities of intrusives, 731
thermoluminescence of ore deposits, 725
uranium, Rum Jungle region, Northern Territory, 119, 826

Prospecting at Cobalt, Ontario, Geochemical (Koehler, Hostetler, and Holland), 378
Proustite, 161, 171
Pseudomorphs, chlorite after tremolite, 320
hematite after magnetite, 257
penninite after pyroxene, 405
pyrite after pyrrhotite, 463
sericite after biotite, 22
thucholite after uraninite and tourmaline, 539
uraninite after pyrite, 159
Pseudo-pipes, 200
Pyrargyrite, 770
Pyrite, 21, 27, 71, 120, 133, 153, 156, 159, 170, 222, 236, 243, 248, 268, 275, 284, 356, 357, 362, 367, 374, 397, 401, 405, 461, 463, 474, 476, 526, 537, 539, 588, 592, 607, 611, 635, 642, 695, 696, 714, 757, 762, 824, 832, 847, 898, 901
Yugoslavia, 454
Pyritic mineralization in the Goudreau area of Algoma, Ontario (Douglas), 310
Pyromorphite, 772
Pyrrhotite, 1, 11, 19, 461, 463, 526, 635

Quarries, Georgia and N. Carolina, 643
Quartz, 9, 21, 68, 71, 124, 137, 156, 158, 222, 331, 358, 360, 397, 400, 424, 461, 474, 504, 508, 619, 637, 641, 648, 728, 755, 757, 762, 766, 804, 832, 881, 889, 901
inclusions, leakage and filling (discussion), 786
Quebec, Lamaque No. 6 vein, 530
Quebec, Vertical zoning at the O'Brien gold mine, Kewagama (Mills), 423
Bourlamaque batholith, radioactivity distribution, 719, 721
copper, alteration at Gaspe mines, 516
gold, Lamaque veins, solution flow, 530
ore bodies and dikes, 407
Preissac-Lacorne lithium district, 511
Quicksilver ores in the Terlingua district, Texas, Transportation and deposition of (Thompson), 175
Quiring, H., on antimony, 479
Quitzow, H. W., on bauxite, 487

Rabbit, J., spectroscopic analysis by, 19
Rabrovo chromite district, Yugoslavia, 484
Radioactive, pronouncedly differentiated pegmatite sill, Lac La Ronge district, northern Saskatchewan (Mawdsley), 616
Radioactive front, 725
Radioactivity, breccia, Hicks Dome, Ill., 899
granites, Katherine-Darwin region, Northern Territory, 828
mineral and thermal waters, Yugoslavia, 538
rocks, 720
Radioactivity—*Continued*
scintillation spectrometer, gamma ray measurement (abstract), 802
Radium, South Australia, Radium Hill mine, 815
Radium Hill uranium mine, South Australia, The geology of the (Parkin and Glasson), 815
Rahlfs, P., on copper, 735
Ramberg, H., on chemical bonds, 565
on metamorphism, 866
Ramdohr, P., on galena, 768
Ramsay, R. H., on White Pine mine, Mich., 677
Rank in coal by differential thermal analysis, Investigation of (Glass), 294
Rankama, K., discussion by, 541
on *C. enigmaticum*, 538
on carbon, 541
Rankama, K., and Sahama, T. G., on metals, 864
on oxyphile and sulfophile elements, 557
Ransome, F. L., on Globe-Miami district, Ariz., 362
on silica, 880
Ransome, F. L., and Calkins, F. C., on Silver Belt, Idaho, 754
Rao, R., review of book by, 547
Rasor, C. A., on uraninite, 360
Rayner, E. O., on cobalt, 564, 570
Read, H. H., review of book by, 225
Realgar, 403, 478
Redox potential, 246, 274
Reed, R. D., on Mohavia, 52
Reiche, P., on sandstone, 88
Reid, I. L., with Schwartz, G. M., abstract by, 124
Reid, W. A., analyses by, 216
Reniérite, 563, 808
Replacement, alteration minerals, Caribou, Colo., 148
bornite by chalcocite, 750
carbonate replacement of rocks, Mindamar, Nova Scotia, 397
chalcopyrite by chalcocite, Ariz., 374
diadochic replacement, 718
germanite by reniérite, 808
gersdorffite by tetrahedrite, 756
hematite by magnetite and carbonate, 275
iron ore, Minnesota, Soudan deposit (abstract), 124
lead-zinc deposits, Yugoslavia, 463
limestone by chalcopyrite, 516
nodules by copper, White Pine district, Mich., 713
plants by uraninite and sulphides, 357
schist by sulphides, Vt., 25
Reviews—
Anleitung zu optischen Untersuchungen mit dem Polarisationsmikroskop (Berek *et al.*), Servos, 224
Bonanza Trail, ghost towns and mining camps of the West (Wolle), Ross, 442

Reviews—Continued
Charnockite problem (Pichamuthu), Bateman, 338
Coalfields of Great Britain (Trueman), Brombert, 665
Composition and origin of the Antrim laterites and bauxites (Eyles), 108
Conversation with the earth (Cloos and Garside), 224
Crystal data, a classification of substances by space groups and their identification from cell dimensions (Donnay, Nowacki, and Donnay), Winchell, 663
Edelsteine und Perlen (Schlossmacher), Servos, 663
Field guide to rocks and minerals (Pough), 225
General chemistry (Pauling), 107; (Rochow and Wilson), 794
Geochemistry (Goldschmidt), 666
Geographical essays (Davis), 914
Geography of North America (Miller, Parkins, and Hudgins), 665
Geology and iron ore deposits of the Granite Mountain area, Iron County, Utah (Mackin), 795
Gisements de fer du Bassin Lorrain (Caillère and Kraut), Dunham, 441
Histoire géologique de la biosphère. La vie et les sédiments dans les géographies successives (Termier and Termier), Fourmarier, 103
Historical survey of petrology (Loewinson-Lessing and Tomkeieff), 913
Leaders in American science, 443
Man, time and fossils (Moore), Brombert, 107
Manual of the polarizing microscope (Hallimond), Servos, 226
Materials survey—Tin, 108
Minerals for atomic energy (Nininger), 912
Minerals for the chemical and allied industries (Johnstone), 913
Minnesota's rocks and waters (Schwartz and Thiel), 795
Morphological analysis of land forms (Penck), 227
Mountain building (Van Bemmelen), 664
Out of the earth (Langford), 547
Pacific Northwest (Freeman and Martin), 794
Pegmatite deposits of the White Picacho district, Maricopa and Yavapai Counties, Arizona (Jahns), Stewart, 335
Pegmatite investigations, 1942-45, New England (Cameron, *et al.*) Peoples, 792
Petrography (Williams, Turner, and Gilbert), 337
Petroleum microbiology (Beerstecher), 912
Reviews—Continued
Physical chemistry of the silicates (Eitel), Lesure, 546
Principles of geomorphology (Thornbury), 794
Recollections of an Indian geologist (Rao), Bateman, 547
Rocks and mineral deposits (Niggli), 545
Rutley's elements of mineralogy (Read), Winchell, 225
Structural geology (Billings), 913
Sudbury Basin (LeBourdais), 442
Tafeln zum Bestimmen der Minerale nach äusseren Kennzeichen (v. Philipsborn), Winchell, 337
Tin, 1951-1953. Review of world tin industry, 226
World population and production (Woytinsky and Woytinsky), 339
Reviews, clerical and critical (discussion), 541
Rhode Island, anthracite, thermal curve, 296
Rhodesia, arkose and graywacke, 245
Rhyolite, 436
Richard, K., and Courtright, J. H., abtract by, 123
Richardson, P. W., on Mindamar mine, Nova Scotia, 391
Richter, D. H., and Abell, J. F., on a microscope heating stage, 787
Richter, D. H., and Ingerson, E., discussion by, 786
Ridland, G. C., abstract by, 123
on uranium, 130
Riley, C. M., communication by, 435
on bloating, 435
Rivers, Minnesota (review), 795
Wisconsin, uranium contents (abstract), 803
Roan Antelope copper deposit of Northern Rhodesia, The origin of the (Davis), 575
Robinson, R. F., on Silver Belt, Idaho, 754
Rochow, E. G., and Wilson, M. K., review of book by, 794
Rocks, aphanites for lightweight aggregate (communication), 435
carbonate rocks, carbonate mineralogy (abstract), 809
field guide (review), 225
metal content, 863
Minnesota (review), 795
petrography, textbook (review), 337
sampling with gold pan, 640
Rocks and hydrothermal ore deposits, The marginal luminescence of certain intrusive (McDougall), 717
Rocks and mineral deposits (review), 545
Rodden, C. J., analyses by, 150
Rodgers, J., on a time scale, 793
review of map and bulletin by, 544
Rogers, A. F., on colloform texture, 162

Rominger, C. L., on copper, 677
Rose, N. A., on Alta Loma sand, Texas, 415
Rosenzweig, A., Gruner, J. W., and Gardiner, L., *Widespread occurrence and character of uraninite in the Triassic and Jurassic sediments of the Colorado Plateau*, 351–361
Rosler, H., on magnetite, 101
Ross, C. P., on Terlingua district, Texas, 176
Ross, C. P., and Hendricks, S. B., on talc, 775
Ross, C. P., and Kerr, P. F., on kaolinite, 776
Ross, V., *The formation of intermediate sulfide phases in the solid state*, 734–752
  review by, 442
Rowe, R. B., *Pegmatitic lithium deposits in Canada*, 501–515
  on pegmatites, 501
Royce, S., on slate, 248
Rubey, W. W., on atmosphere, 245
  on sea water, 180
Rudnick lead-zinc deposit, Yugoslavia, 467
Rücker, A., on Srebrenica district, Yugoslavia, 469
Ruff, A. W., communication by, 779
Rum Jungle province, Northern Territory, Australia, Uranium exploration by the Bureau of Mineral Resources, Geology and Geophysics in the (Fisher and Sullivan), 826
Rust, G. W., on diatremes, 896
Rutile, 21, 651, 822
Rutley's mineralogy (review), 225
Rynearson, G. A., Pomerene, J. B., and Dorr, J. V. N., II, on an unconformity, 660

St. Rose coalfields, Nova Scotia, Petrographic examination of washed, screened and crushed samples of coal from the Sydney and (Hacquebard and Lahiri), 837
Sakamoto, T., on iron and silica, 274
Sales, R. H., and Meyer, C., on alteration, 140, 754
  on bornite, 750
  on sericite, 394
  on silica, 883
Salmo, British Columbia, Canada, The Emerald, Feeney, and Dodger tungsten ore bodies (Ball), 625
Salt, Gulf Coast, salt and cap rock of salt domes (abstract), 805
  Yugoslavia, 454
Salt domes, Gulf Coast salt and cap rock (abstract), 805
  sulphur, origin (abstract), 806
Salt-water encroachment, Angaur Island (abstract), 810
Samples, zircon-rutile mixtures for matching concentrates, 651
Samples of coal from the Sydney and St. Rose coalfields, Nova Scotia, Petrographic examination of washed, screened and crushed (Hacquebard and Lahiri), 837
Sampling, bedrock sampling with gold pan, 640
  coal for petrographic analysis, 843
  cobalt minerals, Cobalt, Ont., 379
  copper in sediments, Mich., 709
  inclusions in Vein No. 6, Lamaque mine, Que., 532
  lignite for petrographic analysis, N. Dak., 97
  uraninite vein, Caribou mine, Colo., 131
Sampson, E., on cherty sediments, 277
Sanders, B. H., on iron ore, 660
Sandstone, Coconino sandstone, Ariz., 88
  White Pine district, Mich., 685, 706
Santillán, M., and Barrera, T., on Alisitos formation, Mexico, 48
Sap, 641
Saprock, 641
Saprolite, 639, 641
Saprolitization, 641
Saskatchewan, Radioactive, pronouncedly differentiated pegmatite sill, Lac La Ronge district, northern (Mawdsley), 616
Saukov, A. A., on mercury, 182
Schalenblende texture, 164
Scheelite, 66, 625, 633, 723
  British Columbia, Salmo area, 529
  Utah, Little Cottonwood stock (communication), 221
Schenck, R., *et al.*, on sulphides, 737
Schlossmacher, K., review of book by, 663
Schmitt, H., *Certain terms of mining geology as defined and used*, 198–204
  The origin of the silica of the bedrock hypogene ore deposits, 877-890
  on ores, 873
  on propylitization, 200
  on silica, 882
Schneiderhöhn, H., on Majdan Pek copper district, Yugoslavia, 476
  on sphalerite, 410
Scholtz, D. L., on chalcopyrite, 596
Schouten, C., on intergrowth, 598
Schuchert, C., on Cretaceous, Baja Calif., Mexico, 55
Schürman Series, 556
Schumacher, F., *The ore deposits of Jugoslavia and the development of its mining industry*, 451–492
  on lead and zinc, 462
Schumacher, F., Stier, K., and Pfalz, R., on ore deposits, 455
Schwartz, G. M., on alteration, 146
  on chalcopyrite, 370, 596, 737
  on silica, 880

Schwartz, G. M., and Reid, I. L., abstract by, 124
Schwartz, G. M., and Thiel, G. A., review of book by, 795
Schwellnus, C. M., on vermiculite, 326
Science, American leaders (review), 443
Scientific Notes and News, 126, 232, 343, 448, 552, 671, 811, 919
Scintillation equipment and counter technique, 149
Scintillation spectrometer use (abstract), 802
Scintillometer surveys, Rum Jungle area, Northern Territory, 834
Sclar, C. B., and Geier, B., abstract by, 808
Scott, A., on colloform texture, 162
Scott, F. J., with Bell, A. M., *Alteration associated with ore at Gaspe copper mines*, 516
Sections—
anthophyllite-vermiculite deposit, Hafafit, Egypt, 320, 322
bauxite deposits, Herzegovina, Yugoslavia, 487
cobalt ore pile and geochemical anomaly, Cobalt, Ont., 385, 387
Copper Cities copper ore body, 373
earth's crust, sial and metallic segregations, 870
Elizabeth mine, Vt., 4, 6
Guadalupe mine, Mexico, 499
iron formation, depositional zones, 242, 278
Jersey lead-zinc deposit, B. C., 526
Lac La Ronge district, Saskatchewan, 621
manganese deposits, Mogollon Rim, Ariz., 89
Montgomery Co., Texas, 414
Nkana copper concession, Northern Rhodesia, 577
Radium Hill mine, South Australia, 819
Salmo area, Brit. Columbia, 630, 636
White Pine area, Mich., 686, 697
Sedimentary facies of iron formation (James), 235; discussion, 905
Sedimentary rocks, textbook (review), 337
Sedimentation (review), 104
iron formations, 235
Sediments, chemical elements, distribution, 565
copper-bearing "shale," Northern Rhodesia, 580, 602
Houston-Galveston region, Texas, 415
iron, Vareš deposit, Yugoslavia, 486
iron formations, 235, 905
magnetite, authigenic origin (communication), 101
manganese, Mogollon Rim, Ariz., 88
ore deposits and magmatization (abstract), 810
shales, uranium and carbon content, 538
uranium deposits, Monument Valley, Ariz. (abstract), 804
White Pine district, Mich., 676, 680, 696
Sediments of the Colorado Plateau, Widespread occurrence and character of uraninite in the Triassic and Jurassic (Rosenzweig, Gruner, and Gardiner), 351
Segregations of sial and metals, 868, 871
Selenium, occurrence in uraninite deposits, Colo. Plateau, 356
Selvig, W. A., *et al.*, on lignite, 95
Semifusain, 857
Sericite, 130, 136, 370, 394, 400, 440
Sericitization, 881
Serpentine, 481, 489
Hafafit area, Egypt, 320
Serpentinization, 214
Servos, K., books received, 796, 914
reviews by, 224, 226, 663
Seyler, C. A., on coalification, 307
Shales, New Albany shale, radioactivity, 900
Nonesuch shale, Mich., 680
ore shale, Roan Antelope district, Northern Rhodesia, 580, 602
uranium and carbon content, 538
Shand, S. J., on ore deposit theories, 877
on pneumatolysis, 204
Shapiro, L., analysis by, 271
Shatter index, 842
Shaw, D. M., on *Corycium*, 542
on trace elements, 866
Shenon, P. J., and McConnel, R. H., on Silver Belt, Idaho, 754
Shepard, F. P., and Emery, K. D., on continental borderland, 59
Shepard, F. P., on faults, 64
Short, M. N., on polybasite, 770
Sial, segregation, 867
Siderite, 316, 469, 485, 753, 755, 757
Silberschiefer, 479
Silica, origin, Hindustan, Kolhan series (discussion), 333
solubility and deposition, 728
uranium extraction, 654
Silica of the bedrock hypogene ore deposits, The origin of the (Schmitt), 877
Silicates, iron formations, 236, 263, 273
physical chemistry (review), 546
Silicic acid, formation by diatoms, 538
Silicification, 370, 516, 518
Bor copper district, Yugoslavia, 474
Sill, Lac La Ronge district, northern Saskatchewan, Radioactive, pronouncedly differentiated pegmatite (Mawdsley), 616
Sills, diabase, Copper Cities area, Ariz., 365
Nipissing diabase, Cobalt, Ont., 379
Silver, C., *Manganese deposits of the Mogollon Rim, Coconino County, Arizona*, 88–91
Silver, 402, 696
melting point and occurrence, 560
New South Wales, Broken Hill deposit (discussion), 783

Silver—*Continued*
Quebec, O'Brien gold mine, 423
United States, mining camps of the West (review), 442
Yugoslavia, 454, 478
Silver Summit mine, Coeur d'Alene district, Idaho, The occurrence of cobalt and nickel in the (Fryklund and Hutchinson, 753
Simpson, D. J., on gravel, 539
Skarn, 633
Skinner, B. J., discussion of paper by, 786
on inclusions, 331
Slags, silicates (review), 547
Slate, graphitic pyritic slates, Lake Superior region, 248
Slickensides, graphite in pegmatite, Mont., 40, 41
Guadalupe mine, Mexico, 496
Smaltite, 71
Smart, W. M., on H, O, and C, 888
Smith, F. G., *Composition of vein-forming fluids from inclusion data,* 205–210
Direction of flow of late stage solutions in the Lamaque No. 6 vein, 530–536
discussion by, 331
on fluids, 885
on gas to liquid ratio, 331
on gold, 429
on inclusions, 206, 530
on pyrite, 401
Smith, F. G., and Little, W. M., on thin sections, 206
Smith, F. G., and Peach, P. A., on inclusions, 530
Smith, H. T., on radial line plot method, 781
Smith, P. S., on gold, 429
Smith, W., on Caribou stock, Colo., 131
Smithsonite, 772
Smyth, C. H., on hematite, 256
Smyth, H. L., and Smith, P. S., on copper, 2
Snider, L. C., on subsidence, 791
Society of Economic Geologists, Program and abstracts of papers to be presented at the Joint Meeting of the Society of Economic Geologists and the Geological Society of America, at Los Angeles, California, November 1–3, 1954, 801
Söhnge, P. G., on bornite, 600
Soils, samples for cobalt content, Cobalt, Ont., 381
Solid state, The formation of intermediate sulfide phases in the (Ross), 734
Solution by coal and some other materials, Extraction of uranium from aqueous (Moore), 652
Solutions, ore fluid and alteration solutions, 871
ore-forming fluids, 727
Solutions in the Lamaque No. 6 vein, Direction of flow of late stage (Smith), 530
Sorby, H. C., on inclusions, 205
Sorenson, R. E., on Silver Belt, Idaho, 754
South Australia, The geology of the Radium Hill uranium mine (Parkin and Glasson), 815
South West Africa, germanite and reniérite, Tsumeb deposit (abstract), 808
pegmatites (abstract), 117
Southwest, A suggested source of the thiophile elements of the Tertiary ore deposits of the (Hillebrand), 863
Spangenberg, K., on magnesite, 489
Spectroscopy, copper, arsenic content (communication), 910
copper ore, Vt., 19
Spencer, A. C., on silica, 880
Spencer, A. C., and Paige, S., on Central district, New Mexico, 869
Spencer, E., and Percival, F. G., discussion of discussion by, 332
on micro-spherulites, 268
Spessartite, 641
Sphaerocobaltite, 356
Sphalerite, 11, 21, 27, 120, 155, 156, 222, 368, 389, 397, 402, 461, 496, 526, 557, 762, 765, 767
Spherites, greenalite, 267
Spieker, E. M., on mid-Cretaceous orogeny, 55
Spiroff, K., on magnetite, 101, 258
Spodumene, 501, 503, 509, 513
Arizona, pegmatite belt (review), 335
Sprigg, R. C., and Whittle, A. W. G., on folds, 818
Springer, G. D., on Cat Lake—Winnipeg River area, Man., 508
Springs, hot-spring systems (abstract), 806
radioactivity, Yugoslavia, 538
Spurr, J. E., on glauconite, 263
Srebrenica lead-zinc deposit, Yugoslavia, 469
Stappenbeck, R., on magnesite, 489
Stari Glog molybdenite deposit, Yugoslavia, 480
Stearns, H. T., on diatremes, 896
Stephenson, T. E., on inclusions, 206
Stevens, R. E., on solutions, 180
Stevenson, J. G. A., on Stirling mine, Nova Scotia, 391
Stevenson, J. S., on chalcopyrite, 408
Stewart, G. W., review by, 335
Stibnite, 71, 478
Stieff, L. R., Stern, T. W., and Milkey, R. G., on ores, 904
Stilpnomelane, 236, 249, 254, 264, 268, 285, 293, 439
Stilpnosiderite, 441
Stock, A., and Cucuel, F., on mercury, 182
Stock, 199, 204

Stockwell, C. H., on Cat Lake—Winnipeg River area, Man., 508
Stokes, R. H., analyses by, 216
Stratigraphic syncline, 3
Stratigraphy, Baja Calif., Mexico, 47, 72
Brazil, Congonhas district (discussion), 659
Coal Measures, Great Britain (review), 665
Copper Cities area, Ariz., 363
Hicks Dome, Illinois, 892
Houston-Galveston region, Texas, 415
Jura-Triassic, Colo. Plateau, 353
Katherine-Darwin region, Northern Territory, 828
Mindamar mining district, Nova Scotia, 391
Roan Antelope copper belt, Northern Rhodesia, 578
Salmo district, B. C., 523, 628
White Pine area, Mich., 676, 679
Streams, iron and silica content, 242, 276
Stringham, B., on silica, 880
on West Mtn. district, Utah, 868
Strøm, K. M., on uranium, 538
Structural syncline, 3
Structure, Arizona, Copper Cities area, 364, 366
Globe-Miami district (abstract), 122
Silver Bell area (abstract), 123
Bor copper district, Yugoslavia, 473
California, Shasta copper-zinc district (abstract), 120
Elizabeth mining district, Vt., 3, 17
grabens, 64
Hicks Dome, Illinois, 891, 893
Houston-Galveston region, Texas, 415
Huronian geosyncline, Mich., 278
Jersey lead-zinc deposit, B. C., 526
Lac La Ronge district, Saskatchewan, 620
New Mexico, Santa Rita intrusive (abstract), 122
New South Wales, Broken Hill area (discussion), 783
porphyry copper deposits, western U. S. (abstract), 122
Radium Hill area, South Australia, 821
Roan Antelope copper belt, Northern Rhodesia, 581, 583
Salmo tungsten district, B. C., 631
structural geology (review), 913
Tennessee, Friends Station—New Market area (abstract), 121
Upper Miss. Valley lead-zinc district (abstract), 120
Washington, Metaline lead-zinc district (abstract), 121
White Pine district, Mich., 690
Yugoslavia, 458
Stylolites, seams in carbonate iron formation, 252, 255, 269, 274
Subsidence and its relation to the withdrawal of ground water in the Houston-Galveston region, Texas, Land-surface (Winslow and Doyel), 413
Suffell, G. G., on ore bodies, 407
Sulfide phases in the solid state, The formation of intermediate (Ross), 734
Sulfophile elements, 557
Sullivan, C. J., *Metallic melting point and ore deposition*, 555–574; discussion, 903, 904
on zoning, 561
Sullivan, C. J., and Fisher, N. H., abstract by, 119
Sullivan, C. J., and Matheson, R. S., on uranium, 831
Sullivan, C. J., with Fisher, N. H., *Uranium exploration by the Bureau of Mineral Resources, Geology and Geophysics, in the Rum Jungle province, Northern Territory, Australia*, 826
Sulphide facies, iron formations, 236, 248, 272
Sulphides, 1, 11, 14, 19, 71, 863
intrusive effects of dikes, 407
uraninite ores, Colo. Plateau, 356
Sulphur, bacterial formation, 538
Majden Pek district, Yugoslavia, 477
origin, salt-dome deposits (abstract), 806
origin of pyritic slates, Mich., 243, 248
White Pine copper district, Mich., 695
Sverdrup, H. U., Johnson, M. W., and Fleming, R. H., on sea water, 180
Sweden, methane, Boliden mine, 537
Sydney and St. Rose coalfields, Nova Scotia, Petrographic examination of washed, screened and crushed coal from the (Hacquebard and Lahiri), 837
Synclines, stratigraphic and structural, 3
Systems, copper sulphides, 734
$HgS—Na_2S—H_2O$ (abstract), 807

Tables, alteration effects, Needle Mtn., Gaspe, Que., 517
chemical analyses, coal, Nova Scotia, 839, 851
dunite, asbestos, vermiculite, N. C., 216
iron formations, 250, 271
ore, Palomas district, New Mexico, 776
rocks, southwestern, U. S., 878
schist, Mindamar area, Nova Scotia, 394
coal, volatile losses and water peaks, 304
cobalt content of glacial material, 383
copper in sediments, Mich., 703
copper sulphides, solid-state reactions, 738, 747
decrepitation temperature of quartz, 533
igneous rocks, firing tests, 437

Tables—*Continued*
inclusions in synthetic quartz, pressure effects, 787
iron formation features, 249
melting points and distribution of elements, 558
mercury, solubility, 189
minerals and uranium, Caribou, Colo., 136, 150
paragenesis, ores, Palomas district, New Mexico, 771
uraninite, Colo., 162
petrographic analysis, lignites, N. Dakota, 94
radioactivity, breccia, Hicks Dome, Ill., 899
rocks, metal content, 864
stratigraphy, Baja Calif., Mexico, 47, 72
Hicks Dome, Illinois, 892
Roan Antelope copper belt, Northern Rhodesia, 578
Salmo district, Brit. Columbia, 628
White Pine district, Mich., 679
uraninite occurrences, Colo. Plateau, 353
uranium extraction by materials, 653, 654
Taconite, 262
Tactite, 524, 633, 882
Talc, 213, 391, 399, 411, 440, 759, 763, 774, 775
Taliaferro, N. L., on Franciscan deposits, Calif., 52
Tammann, G., and Roche, H. J., on sulphide phases, 744
Tammann's Diffusion Parabolic Rate Rule, 734, 745, 749
Tantalite, 506
Arizona, Midnight Owl mine (review), 336
South West Africa, pegmatite deposits (abstract), 117
Taylor, J. H., on iron oxide, 256
Taylor, R. E., abstract by, 805
Technique, aerial photography of study areas, 780
alteration, study method, Caribou, Colo., 135
arsenic determination in native copper (communication), 909
bloating of igneous rocks, 436
crystal identification by space groups (review), 663
decrepitation of quartz, 532
determination of interface of waters, 186
determinative tables for minerals (review), 337
digenite formation, 736
extraction of uranium by materials, 653
gold pan, 639, 644, 646
heating of inclusions in quartz (discussion), 786
lateritic ore, reconnaissance and screening tests, Cuba (abstract), 118
Technique—*Continued*
luminescence of rocks, 720
mapping, Rum Jungle area, Northern Territory, 833
monazite exploration (abstract), 119
petrographic analyses of coal, 843
plaster of Paris embedding of lignite, 96
polarization microscope optics (reviews), 224, 226
sampling cobalt content of soils, Ont., 381
scintillation equipment and counter technique, 149
scintillation spectrometer use (abstract), 802
Teichmüller, M., on coal, 92
Telethermal deposits, 560
Tennantite, 21, 402
Tennessee, geologic map, east Tennessee (review), 544
zinc, Friends Station—New Market area (abstract), 121
Terlingua district, Texas, Transportation and deposition of quicksilver ores in the (Thompson), 175
Termier, H., and Termier, G., review of book by, 103
Terms of mining geology as defined and used, Certain (Schmitt), 198
Terzaghi, K., and Peck, R. B., on clays, 420
Tetrahedrite, 71, 753, 757, 768
Bosnia, Yugoslavia, 477, 479
Texas, Land-surface subsidence and its relation to the withdrawal of ground water in the Houston-Galveston region (Winslow and Doyel), 413; discussion, 790
Transportation and deposition of quicksilver ores in the Terlingua district (Thompson), 175
Textbook, chemistry (reviews), 107, 794
geochemistry (review), 666
geography, North America (review), 665
geomorphology (review), 794
historical geology (review), 103
mineralogy (review), 225
petrography (review), 337
Textures, colloform, carbonates, Nova Scotia, 395
uraninite ore, Colo., 159, 162
eutectic texture of uraninite and silver minerals, 154
spodumene aggregates, Canada, 504
sulphide minerals, Roan Antelope ore, Northern Rhodesia, 595
Thallium, melting point and zoning, 557
Thermal analysis, Investigation of rank in coal by differential (Glass), 294
Thermal springs, alteration (abstract), 806
radioactivity, Yugoslavia, 538
Thermoluminescence, 720, 722

Thesis, incorporation of aerial photos (communication), 779
Thiel, G. A., on sulphides, 248
Thiessen classification of coal, 92
Thiophile elements of the Tertiary ore deposits of the southwest, A suggested source of the (Hillebrand), 863
Thompson, A. P., on copper, 2
Thompson, G. A., *Transportation and deposition of quicksilver ores in the Terlingua district,* Texas, 175–197
Thompson, J. B., on folds, 5
Thoreau, J., and Trieu de Terdonck, R. du, on uraninite, 154
Thorium, 899, 912
  scintillation spectrometer for gamma ray measurement (abstract), 802
Thornbury, W. D., review of book by, 794
Thucholite, 537
Thuringite, 265
Thurlow, E. E., and Jarrard, L. D., abstract by, 125
Thurlow, E. E., and Wright, R. J., on Silver Belt, Idaho, 754
  on uraninite, 166
Tin (review), 108
  industry review (review), 226
  melting point and occurrence, 562
Titaniferous gabbro, Egypt, 78
Titcomb, H. A., *et al.,* on Trepča area, Yugoslavia, 462
Tolmachev, I. M., on uranium, 654
Tolman, C., on diabase, 408
Tolman, C. F., on aquifers, 419
Tolman, C. F., and Poland, J. E., on subsidence, 419
Tomkeieff, S. I., review of translation by, 913
Torbernite, 832
Tourmaline, 21, 509, 594, 604, 637
Touwaide, M. E., on copper, 72
Transvaal, gold-uranium, Witwatersrand, genesis, 537
Traverse, A., *A method for the petrographic analysis of commercially delivered lignite,* 92–100
Tremblay, L. P., on igneous rocks, 511
Tremolite, 12, 24
Trepča lead-zinc deposit, Yugoslavia, 462
Triassic and Jurassic sediments of the Colorado Plateau, Widespread occurrence and character of uraninite in the (Rosenzweig, Gruner, and Gardiner), 351
Triphylite, 508, 510
Trueman, Sir A., review of book by, 665
Tschermak, G., on volcanic phenomena, 888
Tubandt, C., Reinhold, H., and Neumann, A., on silver, 748
Tumors, 64
Tungsten, Baja Calif. deposits, Mexico, 66
  British Columbia, Salmo area, 529
Tungsten—*Continued*
  Colorado, Cold Spring mine (abstract), 123
  Nevada-Baja Calif. deposits, 60
  occurrence, 563
  scheelite, Little Cottonwood stock, Utah (communication), 221
Tungsten ore-bodies, Salmo, British Columbia, Canada, Emerald, Feeney and Dodger (Ball), 625
Tunisia, lead-zinc deposits, genesis, 571
Turner, F. J., on greenschist facies, 245
Turner, F. J., and Hutton, C. O., on stilpnomelane, 264
Turner, F. J., and Verhoogen, J., on basalt, 865
  on dunite, 213
  on metamorphism, 200
Turquoise, 368
Tuttle, O. F., and Friedman, I., on solutions, 210
Twenhofel, W. H., on diagenesis, 274
Tyler, S. A., on iron, 238
Tyler, S. A., and Twenhofel, W. H., on iron formations, 243, 274
Tyuyamunite, 360

Udden, J. A., on ores, 183
Umpleby, J. B., and Jones, E. L., Jr., on Silver Belt, Idaho, 754
Underground water, Texas, Houston-Galveston region, withdrawal and subsidence (discussion), 790
Union South Africa, banded ironstones, 240, 256
U.S.S.R., black mud deposition, Black Sea coast, 539
  melnikowite, 258
United Kingdom, coal fields (review), 665
  iron formations, 257
United States, Bonanza Trail, ghost towns and mines (review), 442
  copper, porphyry deposits, structure (abstract), 122
  ore deposits, thiophile elements, southwest U. S., 863
  Pacific Northwest (review), 794
  scientific leaders (review), 443
Unkovskaya, V., on uranium, 652
Uralite, 404
Uraninite, 507, 537, 539, 616, 622, 804, 912
Uraninite deposit at Caribou, Colorado, Mineralogy of a (Wright), 129
Uraninite in the Triassic and Jurassic sediments of the Colorado Plateau, Widespread occurrence and character of (Rosenzweig, Gruner, and Gardiner), 351
Uranium, accumulation in plants (abstract), 803
  Arizona, Monument Valley (abstract), 804

Uranium—*Continued*
Australia, Edith River deposits (abstract), 118
Rum Jungle province (abstract), 119
Boulder batholith, Mont. (abstract), 803
Colorado, Central City deposit, origin, 731
Colorado Plateau (discussion), 904
estimation of reserves (abstract), 805
melting point and occurrence, 562
migration into rock, Colo., 150
Montana, Boulder batholith deposits (abstract), 125
origin of deposits (abstract), 118
river content, Wis. (abstract), 803
scintillation spectrometer for gamma ray measurement (abstract), 802
Utah, Big Indian Wash-Lisbon Valley area (abstract), 804
Uranium deposits, Genesis of the Witwatersrand gold (Miholić), 537
Uranium exploration by the Bureau of Mineral Resources, Geology and Geophysics in the Rum Jungle province, Northern Territory, Australia (Fisher and Sullivan), 826
Uranium from aqueous solution by coal and some other materials, Extraction of (Moore), 652
Uranium mine, South Australia, The geology of the Radium Hill (Parkin and Glasson), 815
Urey, H., and Greiff, L. J., on deuterium, 730
Utah, iron, Iron Springs deposit, origin, 731
map, Granite Mtn. area (review), 795
rocks, alteration, Bingham area, 878
scheelite, Little Cottonwood stock (communication), 221
uraninite, Colo. Plateau deposits, 351
uranium, Big Indian Wash-Lisbon Valley area (abstract), 804
Uvarovite, 484
Uvite, 605

Vaes, J. F., on reniérite, 563
Valleriite, 21
Vanadinite, 772
Vanadium, 564, 569
Colorado Plateau (discussion), 904
estimation of reserves (abstract), 805
occurrence in uraninite deposits, Colo. Plateau, 360
Van Bemmelen, R. W., review of book by, 664
Van der Veen, R. W., on intergrowth, 596
Van Hise, C. R., and Bayley, W. S., on slate, 248
Van Hise, C. R., and Leith, C. K., on iron formation, 237, 259, 276
Vanderwilt, J. W., and King, R. U., abstract by, 125
Vanning, 645
Vareš iron ore district, Yugoslavia, 485
Veatch, J. A., on chromite, 49
Vein, Direction of flow of late stage solutions in the Lamaque No. 6 (Smith), 530
Vein-forming fluids from inclusion data, Composition of (Smith), 205
Veins, carbonate veins, Goudreau, Ont., 315
Cobalt district, Ont., 379
gold-quartz, Alamo district, Baja Calif., Mexico, 68
lead-zinc, Yugoslavia, 469, 471
O'Brien gold mine, Que., 424, 427
Roan Antelope copper belt, Northern Rhodesia, 608
silica, origin, 878
silver, Coeur d'Alene district, Idaho, 754
tungsten, Colorado, Cold Spring mine (abstract), 124
uranium, Radium Hill mine, South Australia, 821
uranium-quartz, Rum Jungle area, Northern Territory, 832
Verhoogen, J., on crystals, 194
Vermiculite, 216
Nevada, origin, Southern Virgin Mtns. (abstract), 809
Vermiculite at the Day Book dunite deposit, Yancey County, North Carolina, Notes on the dunite and the geochemistry of (Kulp and Brobst), 211
Vermiculite deposit of Hafafit, Eastern Desert, Egypt, Anthophyllite (Amin and Afia), 317
Vermont, The Elizabeth copper mine (McKinstry and Mikkola), 1
Vernadsky, W., on thucholite, 537
Vernadsky, V. I., Vinogradov, A. P., and Teis, R. V., on hydrous minerals, 729
Vine, J. D., and Moore, G. W., on uranium, 652
Vinogradov, A. P., on diatoms, 538
Virginia, anthracite, thermal curve, 297
Vitrain, 838, 841
Vitrinite, 845, 847
Vitrophyr, 204
Volcanism, iron addition, to sea water, 237, 276
Von Gumbel, C. W., on magnetite, 101
Vugs, 789
Caribou, Colo., 140, 159, 160
magnetite crystals, Minn., 101
ores, Palomas district, New Mexico, 764, 771
tetrahedrite veins, Silver Summit mine, Idaho, 755, 757
Vulcanism, Goudreau area, Ont., 312

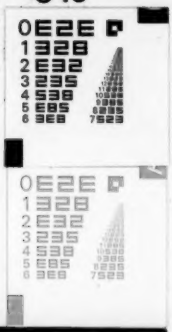
Wagner, C., calculations by, 738
on silver, 748
Wagner, P. A., on ironstones, 257, 276

Walker, J. F., on Salmo area, B. C., 628
Wandke, A. D., Jr., on blue chalcocite, 737
Wansbrough, V. C., mineral industry, Canada (review), 547
Washington, H. S., on oxyphile elements, 561
Washington, Metaline lead-zinc district, structure (abstract), 121
Wasserstein, B., on galena, 768
Water, system $HgS—Na_2S—H_2O$ (abstract), 807
uranium extraction, 658
Water of hydration, isotopic composition, 729
Watson, K. D., *Paragenesis of the zinc-lead-copper deposits at the Mindamar mine, Nova Scotia,* 389–412
Weathering, coal, Illinois, thermal effects, 302, 304
iron formation, 276, 280
laterite formation, Conakry, French Guinea (discussion), 905
lateritic nickel-cobalt ore, Cuba (abstract), 117
ore deposits and magmatization (abstract), 810
Rum Jungle uranium province, Australia (abstract), 119
saprolite and saprolitization, 641
Weaver, C. E., *et al.,* on conglomerates, 50
Weed, W. H., on copper, 1
Weeks, L. G., on Gulf of Calif.—Imperial Valley trough, 64
Weeks, L. J., on Stirling area, Nova Scotia, 391
Well on Hicks Dome, Hardin County, Illinois, Explosion pipe in test (Brown, Emery, and Meyer), 891
Weller, J. M., *et al.,* on explosion breccia, 896
Weller, S., and St. Clair, S., on St. Peter sand, 893
Wendt, A. F., on copper, 2
Wentworth, C. K., Mason, A. C., and Davis, D. A., abstract by, 810
West Virginia, coal, thermal curves, 299
Wheeler, H. A., on copper, 2
Whishaw, Q. G., *The Jersey lead-zinc deposit, Salmo, B. C.,* 521–529
White, D., on Steamboat Springs, Nev., 889
White, D. E., abstract by, 806
on antimony, 187
White, D. E., and Brannock, W. W., on water, 184
White, D. E., and Gonzáles Reyna, J., on solutions, 187
White, D. E., and Guiza, R., Jr., on solutions, 187
White, W. S., on copper, 714
White, W. S., and Billings, M. P., on marble, 12
White, W. S., and Eric, J. H., on copper, 2
White, W. S., and Jahns, R. H., on synclines, 3
White, W. S., and Wright, J. C., *The White Pine copper deposit, Ontonagon County, Michigan,* 675–716
White, W. S., Cornwall, H. R., and Swanson, R. S., on Portage Lake lavas, Mich., 676
White Pine copper deposit, Ontonagon County, Michigan (White and Wright), 675
Whitehead, W. L., on coal, 295
Whitehead, W. L., and Breger, I. A., on vacuum technique, 295
Whiting, F. B., *Ore controls at the Guadalupe mine, Nuevo Leon, Mexico,* 493–500
Whittlesey, C., on copper, 677
Wiik, H. B., analysis by, 776
Willard, M. E., on cobalt, 753
Williams, H., Turner, F. J., and Gilbert, C. M., review of book by, 337
Wilson, G., on Kopaonik Mtns., Yugoslavia, 465
Wilson, H. S., on Lamaque mine, Que., 530
Wilson, I., on conglomerates, 50
Wilson, I., and Veytia, M., on manganese, 73
Wilson, M. E., on ore bodies, 407
Winchell, A. N., on graphite, 34
on olivine, 217
Winchell, A. N., and Winchell, H., on ankerite, 604
on carbonate, 395
Winchell, H., reviews by, 225, 337, 663
Winslow, A. G., and Doyel, W. W., *Land-surface subsidence and its relation to the withdrawal of ground water in the Houston-Galveston region,* Texas, 413–422; discussion, 790
Wisconsin, copper, Nonesuch shale deposits, 715
iron formations, sedimentary facies, 235
uranium contents of rivers (abstract), 803
zinc-lead district, structure (abstract), 120
Wisser, E., *Geology and ore deposits of Baja California, Mexico,* 44–76
Witkind, I. J., abstract by, 804
Wittich, E., on iron, 67
Witwatersrand gold-uranium deposits, Genesis of the (Miholić), 537
Wolfe, O. W., abstract by, 810
Wollastonite, 25, 517
Wolle, M. S., review of book by, 442
Wood, uranium extraction by pine, 654, 656
Woodford, A. O., and Harriss, T. F., on Sierra de San Pedro Mártir, Mexico, 48

Woolnough, W. G., on barred basins, 280
World, population and production (review), 339
Woytinsky, W. S., and Woytinsky, E. S., review of book by, 339
Wright, H. D., *Mineralogy of a uraninite deposit at Caribou, Colorado*, 129–174
Wright, J. C., with White, W. S., *The White Pine copper deposit, Ontonagon County, Michigan*, 675
Wulfenite, 469, 772
Wyman, R. V., discussion by, 904
Wyoming, hot-spring systems (abstract), 806

Xenotime, 642, 650
X-ray study, copper sulphides, 735
  crystal identification, textbook (review), 663
  uraninites, 355
    Colo., 169

Yagishita, H., on coal, 295
Yates, R. G., and Thompson, G. A., on Terlingua district, Texas, 176
Yellowknife-Beaulieu district, N. W. T., 504
Yoder, H. S., Jr., on metamorphism, 214
Yugoslavia, radioactivity, mineral and thermal waters, 538
Yugoslavia and the development of its mining industry, The ore deposits of (Schumacher), 451

Zinc, California, Shasta district (abstract), 120
  geochemical anomalies, 387
  melting point and zoning, 557
  New South Wales, Broken Hill deposit (discussion), 783
Zinc—*Continued*
  Tennessee, Friends Station—New Market area (abstract), 121
  Upper Miss. Valley, structure (abstract), 120
  Washington, Metaline district (abstract), 121
  Yugoslavia, 454, 460
Zinc deposit, Salmo, B. C., The Jersey lead (Whishaw), 521
Zinckenite, 738
Zinc-lead-copper deposits at the Mindamar mine, Nova Scotia, Paragenesis of the (Watson), 389
Zinnwaldite, 508
Zircon, 642, 648, 651
Zletovo lead-zinc district, Yugoslavia, 471
Zobell, C. E., on sediments, 275
Zone of magmation, 863, 871
Zones, mineral deposits, Yugoslavia, 457
Zones of alteration, Caribou, Colo., 134
Zoning, Copper Cities copper deposit, Ariz., 371
  copper sulphides, Roan Antelope, Northern Rhodesia, 589, 610
  El Triunfo-San Antonio area, Baja Calif., Mexico, 71
  hydrophilic series and zoning, 152
  lithium pegmatites, 506, 511
  Little Cottonwood stock, Utah (communication), 222
  luminescence of minerals near geologic units, 720
  metamorphic rocks, Vt., 5
  ore deposits, 556, 557
  pegmatites (review), 792
    Arizona, White Picacho district (review), 335
Zoning at the O'Brien gold mine, Kewagama, Quebec, Vertical (Mills), 423
Zuckert, R., on uraninite, 154

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